CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis establishes the relationship between manufacturer selling price (MSP) and energy consumption for the walk-in coolers and freezers covered in this rulemaking. The cost-energy consumption relationship serves as the basis for the cost/benefit calculations for individual customers, manufacturers, and the Nation. In determining this relationship, the U.S. Department of Energy (DOE) estimates the increase in manufacturer production cost (MPC) associated with technological changes that reduce the energy consumption of baseline models, then converts each MPC to MSP by applying a multiplier to determine the manufacturer markup.

The primary inputs to the engineering analysis are baseline information and data for each equipment class addressed in the market and technology assessment (chapter 3 in the preliminary TSD) and technology options from the screening analysis (chapter 4 in the preliminary TSD). Additional inputs include cost and energy consumption data that DOE estimated using a cost model and an energy consumption model, respectively. The primary output of the engineering analysis is a set of cost-energy consumption curves and a manufacturer markup multiplier used to convert MPC to MSP. In the subsequent markups analysis (chapter 6 in the preliminary TSD), DOE determines customer prices by applying distribution markups, sales tax, and contractor markups. After applying these markups, the data serve as inputs to the energy use analysis (chapter 7 in the preliminary TSD) and the life cycle cost and payback period analyses (chapter 8 in the preliminary TSD).

In this chapter, DOE discusses representative baseline units, methodology used to develop MPC, markups to MSP, sensitivity to material prices, methodology used to estimate energy consumption, cost-energy consumption curves, normalization of energy consumption metrics, and design options.

5.2 METHODOLOGY OVERVIEW

This section describes the analytical methodology used in the engineering analysis. In this rulemaking, DOE is adopting a design-option approach, which calculates the incremental costs of adding specific design options to a baseline model. As discussed in Chapter 2, DOE is considering the envelope and the refrigeration system separately. Consequently, DOE developed separate engineering curves for envelopes and refrigeration systems while using the same general cost and energy consumption models for each component. Furthermore, for each equipment class of both envelopes and refrigeration systems, DOE analyzed different size equipment to assess how energy use varies with size. DOE specified a small- and large-capacity unit of each class for the refrigeration system analysis, and a small, medium, and large size envelope of each class for the envelope analysis. A baseline unit was specified for each equipment class based on equipment offerings currently on the market. See chapter 3 of the preliminary TSD for a detailed description of the equipment classes and section 5.4.6 below for additional detail on the different size machines analyzed.

For each equipment class and size, DOE developed both an envelope cost and a refrigeration system cost using a manufacturing cost model. DOE also developed an envelope energy consumption and a refrigeration system energy consumption using an energy consumption model. DOE combined the cost analyses and energy consumption analyses to obtain a relationship between cost and energy consumption, expressed as a plot of cost vs. energy consumption for each design option, for refrigeration systems and envelopes. These plots appear in section 5.5.

5.3 COST MODEL

The cost model is the first of two key analytical models used in constructing cost-efficiency curves. A cost model was used to estimate the baseline cost of an envelope and a refrigeration system of a walk-in cooler or freezer. This cost model was adapted from the cost models for beverage vending machines and commercial refrigeration equipment, as walk-ins share many of the same general components and features. The cost model was significantly modified to add features that are unique to walk-in envelopes and refrigeration systems, such as foam insulation and large fan assemblies. DOE also modified the model for walk-in coolers and freezers using input from stakeholders on unit MPC estimates and assumptions to confirm accuracy.

The cost model is based on production activities and divides factory costs into the following categories:

Table 5.3.1 Cost Model Output Classifications

Major Category	Sub-Category	Description
Material Costs	Direct	Raw materials (i.e. coils of sheet metal) and purchased parts (i.e. fan motors, compressors, etc.)
	Indirect	Welding rods, die oil, release media
Manufacturing Labor	Assembly	Parts / unit assembly on manufacturing line
	Fabrication	Conversion of raw material into parts ready for assembly
	Indirect	Fraction of overall labor not associated directly with product manufacturing, i.e. forklift drivers, quality control, for example.
	Supervisory	Fraction of above labor, is paid a higher wage
Depreciation	Equipment, Conveyor, Building	Straight line depreciation over expected life.
	Tooling	Cost is allocated on a per-use basis or obsolescence, whichever is shorter.
Other Overhead	Utilities	A fixed fraction of all material costs meant to cover electricity and other utility costs.
	Maintenance	Based on installed equipment and tooling investment.
	Property Tax and Insurance	A fixed fraction based on total unit costs.

The cost model analysis created cost estimates for each of the walk-in coolers and freezers analyzed. The cost model uses specific assumptions to provide cost estimates, and the following sections describe these assumptions.

5.3.1 Cost Model Overview

This section provides a general overview of how the cost model works. The first step in the cost model analysis is to create a structured bill of materials (BOM) as a basis for all future cost analysis. Typically, products or equipment are purchased and disassembled piece-by-piece until no parts are left over. Every component is cataloged, analyzed, and photographed. Items are classified by sub-assembly, function, and any fabrication and assembly operations that DOE estimates the manufacturer to perform in their facility. For example, DOE distinguishes whether parts are purchased (and hence are limited to assembly) or whether the components are fabricated on site (requiring equipment, labor, etc. prior to integration into the final product). DOE consults a wide range of industry sources for purchased parts and raw materials to help estimate total material costs. Additionally, DOE conducts site visits to confirm which parts are purchased versus being fabricated on-site, and why.

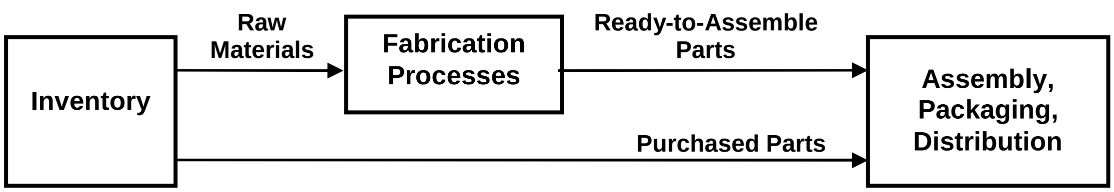

Figure 5.3.1 Production Flow in BOM

For the WICF analysis, DOE did not conduct a tear-down analysis based on equipment available for purchase due to the size and complexity of purchasing entire walk-in cooler systems. Instead, DOE visited multiple manufacturing facilities to observe variability in manufacturing techniques, noting materials, purchased parts, and labor used. Additionally, DOE conducted interviews with manufacturers to ensure the accuracy of the WICF model's methodology and pricing.

When appropriate, a supplementary method, called a catalogue teardown, was used to supplement the already-gathered data. A catalogue teardown is based on published manufacturer product literature and supplementary component data. Typically, it uses a similar product that was torn down as a starting point, and differences in construction, purchased parts, etc. are then accounted for. A catalog teardown thus serves the purpose of greatly expanding the number of units and capacity ranges under consideration without the significant expense attached to purchasing a very wide range of equipment.

Besides noting all material, labor, and overhead costs, the cost model also estimates the facility requirements for a given production volume. Thus, the bill of materials (BOM) will generate detailed equipment, tooling, and space requirements for a given production volume. For this rulemaking, incoming and outgoing freight were accounted for since they have a significant impact on production and shipping costs due to the large physical volume of WICF panels. However, the outbound freight cost is not considered a manufacturing cost, but is added as part of the manufacturer selling price. DOE based assumptions about the sourcing of parts and in-house fabrication on industry experience, information in trade publications, and discussions with manufacturers.

In sum, DOE assigned costs of labor, materials, and overhead to each part, whether purchased or produced in-house. DOE then aggregated single-part costs into major assemblies (e.g., panel assembly, door assemblies, condensing unit, evaporator unit, controls, and packaging), and summarized these costs in a spreadsheet.

5.3.2 Structure of the Cost Model Spreadsheet

Manufacturer practices and cost structure play an important role in estimating the final cost of the equipment. Depending on conditions in the marketplace regarding capital, labor, and other factors, a manufacturer will choose different approaches to manufacturing its products, ranging from outsourcing all production to being completely vertically integrated. DOE attempts to capture a representative view of industry economic and manufacturing conditions through its model, teardowns, and site visits.

For this particular industry, DOE noted that manufacturers generally assembled panel systems with a mix of raw materials (i.e. converted sheet metal, foam, etc.) and purchased parts (i.e. fasteners, door hardware, cut-to-length seals, etc.). WICF refrigeration systems were generally purchased either as complete assemblies or modified in-house using purchased parts. For the raw materials being converted to ready-to-assemble parts, DOE estimated manufacturing process parameters, e.g., manufacturing equipment use and time for each item, the required initial material quantity, scrap, etc. to determine the value of each component. All parameters related to manufacture and assembly are then aggregated to determine facility requirements at various manufacturing scales and the final unit cost.

The final equipment cost includes the material, labor, depreciation, and overhead costs associated with the manufacturing facility. The material costs include both raw materials and purchased part costs. The labor costs include fabrication, assembly, and indirect and overhead (burdened) labor rates. The depreciation costs include manufacturing equipment depreciation, tooling depreciation, and building depreciation. The overhead costs include indirect process costs, utilities, equipment and building maintenance, and rework. The following sections describe the cost model assumptions related to material prices, purchased parts and factory parameters.

5.3.2.1 Material Prices

DOE determined the cost of raw materials on the basis of manufacturer feedback, American Metals Market, [i] and Bureau of Labor Statistics Producer Price Index (PPI) data. [ii] To help address the impact of significant metal price fluctuations, metal price data is averaged over a five-year period. For non-metal materials, such as plastics, DOE uses the most current material prices it can obtain as opposed to a five-year average.

5.3.2.2 Fabricated Parts and Purchased Parts

DOE characterized parts based on whether manufacturers fabricated them in-house or purchased them from outside suppliers. For fabricated parts, DOE estimated initial raw material dimensions to account for scrap. For scrap materials that are recyclable, DOE assigned a scrap credit that is a fraction of the base material cost (i.e. high-cost rifled copper tubing is recycled on the basis of the scrap value for plain copper). Non-recyclable materials incur a disposal cost for all scrap.

For purchased parts, DOE estimated the purchase price for OEMs based on discussions with manufacturers and suppliers, expected shipment volumes, and industry experience. Whenever possible, DOE obtained price quotes directly from suppliers of the manufacturers for the units being analyzed. DOE assumed that the components in Table 5.3.2 were purchased from outside suppliers.

Table 5.3.2 Purchased WICF Components

Assembly	Purchased Sub-Assemblies
Refrigeration Equipment Components	
Condensing Unit	Compressor
	Condenser Fan Blade
	Condenser Fan Motor
	Condenser Coil
	Filter/Dryer
	Hi/Low Pressure Switch
	Accumulator
	Valves
	Plastic Parts
Evaporating Unit	Evaporator Fan Blade
	Evaporator Fan Motor
	Evaporator Coil
	Defrost Heater Rods
	Distribution Header
	TXV/EEV/Orifice
	Plastic Parts
Controls	Control Boards
	Capacitors, transformers, contactors, etc.
Envelope Components	
Non-Display Door Assembly	Hinges
	Kick Plate
	Door closing mechanism
	Latch Assembly
	Gasketing
	Door Sweep
	Camlocks
	Temperature Gauge
	Heater wire (for freezers only)
	Heater accessories (for freezers only)
Display Door Assembly	Pre-Assembled Unit (glazing, heater wire, light fixtures, hinges etc)
Panel Assembly	Camlocks
	Gaskets
	Insulation (for board stock only)
	Caulking for panel-to-floor interface

As previously stated, variability in the costs of purchased parts can account for large changes in the overall MPC values calculated. Purchased part costs can vary significantly based on the quantities desired and the component suppliers chosen. The purchased part prices used in this study were typical values based on estimated production volume and other factors. However, variability in these prices would exist in reality on a case-by-case basis.

Due to the great diversity of manufacturing scale in the WICF industry, DOE estimates that the purchased parts costs in particular could vary significantly by manufacturer. Purchased parts make up roughly 60-70% of the MPC for refrigeration equipment and 20-30% of the envelope MPC. Additionally, some parts like heat exchanger coils, control systems, and foam insulation may be produced in-house by some manufacturers and purchased by others, changing likely overall system costs and investment requirements. For the preliminary analysis, DOE determined an average for the MPC based on an estimated market share of 50 percent for manufacturers who purchase the coils and 50 percent for manufacturers who make the coil in-house.

DOE also made several assumptions regarding the purchase costs of control systems, including defrost control, fan motor control, and floating head pressure control. In surveying manufacturers and suppliers, DOE determined that the cost of these components varies widely among manufacturers and suppliers. Often, several of these functions are packaged together into a single control system. Most manufacturers and suppliers apply a significant markup to these control systems – both single-function and multi-function – that can be many times that of the components used to make them; this markup accounts for the labor and, more importantly, the expertise of the maker of these parts. The costs used in the engineering model reflect the price DOE estimated that a manufacturer in the walk-in industry would pay to purchase the controls from a supplier; however, DOE recognizes that a walk-in manufacturer who makes these components in-house would not see the same cost, yet would be able to charge a premium on to the purchaser.

5.3.2.3 Factory Parameters

Certain factory parameters, such as fabrication rates, labor rates, and wages also affect the cost of each unit produced. DOE factory parameter assumptions were based on internal expertise and manufacturer feedback. Table 5.3.3 and Table 5.3.4 below list the factory parameter assumptions used in the cost model.

Table 5.3.3 Factory Parameter Assumptions, Refrigeration Equipment

Parameter	Estimate
Name-plate Production Capacity (units/year)	30,000
Actual Annual Production Volume (units/year)	12,000
Work Days Per Year (days)	250
Assembly Shifts Per Day (shifts)	2
Fabrication Shifts Per Day (shifts)	2.5
Fabrication Labor Wages ($/hr)	16
Assembly Labor Wages ($/hr)	16
Assembly Worker Hours Per Year	3,600
Fabrication Worker Hours Per Year	4,500
Length of Shift (hrs)	8
Units Per Day	48
Average Equipment Installation Cost (% of purchase price)	10%
Fringe Benefits Ratio	50%
Indirect to Direct Labor Ratio	33%
Average Scrap Credit (relative to base material cost)	30%
Non-recyclable trash cost ($/lb)	0.01
Building Cost ($/ft^2)	100170
Worker Downtime	10%
Building Life (in years)	3025
Burdened Assembly Labor Wage ($/hr)	24
Burdened Fabrication Labor Wage ($/hr)	24
Supervisor Span (workers/supervisor)	25
Supervisor Wage Premium (over fabrication and assembly wage)	30%

Table 5.3.4 Factory Parameter Assumptions, Envelope

Parameter	Estimate
Name-plate Production Capacity (complete walk-ins/year)	30,000
Actual Annual Production Volume (complete walk-ins/year)	12,000
Work Days Per Year (days)	250
Assembly Shifts Per Day (shifts)	2
Fabrication Shifts Per Day (shifts)	2.5
Fabrication Labor Wages ($/hr)	16
Assembly Labor Wages ($/hr)	16
Assembly Worker Hours Per Year	3,600
Fabrication Worker Hours Per Year	4,500
Length of Shift (hrs)	8
Panels Per Day	48
Average Equipment Installation Cost (% of purchase price)	10%
Fringe Benefits Ratio	50%
Indirect to Direct Labor Ratio	33%
Average Scrap Credit (relative to base material cost)	30%
Non-recyclable trash cost ($/lb)	0.01
Building Cost ($/ft^2)	170
Worker Downtime	10%
Building Life (in years)	25
Burdened Assembly Labor Wage ($/hr)	24
Burdened Fabrication Labor Wage ($/hr)	24
Supervisor Span (workers/supervisor)	25
Supervisor Wage Premium (over fabrication and assembly wage)	30%

5.3.3 Downstream Analyses

The MSPs derived in the engineering analysis are inputs to the life-cycle cost analysis (LCC) and the manufacturer impact analysis (MIA). In the LCC, the MSPs are necessary to calculate the total installed cost of each unit. In the MIA, DOE constructs a number of scenarios that analyze how different pricing schemes impact manufacturers financially. Hence, both the MSP and the direct production cost components of MSP are important drivers of results in the MIA. In chapters 8 and 12 of the preliminary TSD, respectively, DOE discusses how the engineering analysis results are used for those sections in greater detail.

5.3.4 Manufacturer Selling Price Estimates

At each stage of the distribution chain, manufacturers, wholesalers, and distributors apply a markup to cover their operating costs and profit margins. In the engineering analysis, DOE determined a manufacturer markup, and applied this markup to the MPC to arrive at the MSP for each equipment class. Wholesaler, distributor, and other markups are determined in the markups analysis (see chapter 6 of the preliminary TSD).

The manufacturer markup is a market-share-weighted average value for the industry. DOE developed this markup by examining several WICF manufacturers' gross margin information from annual reports and Securities and Exchange Commission 10-K reports. The manufacturers analyzed by DOE account for the majority of the WICF market, and some of these companies are subsidiaries of more diversified parent companies that manufacture equipment other than walk-in coolers and freezers. Because the 10-K reports do not provide gross margin information at the subsidiary level, the estimated markups represent the average markups that the parent company applies over its entire range of equipment offerings.
DOE evaluated markups for 2004 through 2008, calculating the manufacturer markup as 100/(100 – average gross margin), where average gross margin is calculated as revenue – cost of goods sold. Taking this information into consideration, DOE is using an industry-wide manufacturer markup of 1.39 in the engineering analysis.

The cost of specific models—or cost to an individual manufacturer to produce walk-in cooler or freezer equipment—will vary depending on the equipment's precise design and features, actual manufacturing processes, the equipment mix in the factory, and other production factors. There are also considerable differences in the levels of vertical integration that affect cost structure and, hence the cost of equipment. Companies with a large market share and/or revenue base tend to be more vertically integrated than lower-volume competitors.

In order to calculate the most likely selling price, DOE researched the industry to determine the markups that manufacturers charge on top of the MPC. DOE determined that the average markup for the industry is 1.39. The MSP is a product of the MPC and the manufacturer markup, added to the outbound freight cost from the manufacturer to the distributor (freight from the distributor to other points in the distribution chain, including the end-user, is covered in downstream analyses. The components of MSP are shown in greater detail in Figure 5.3.2.The outbound freight cost is captured in the non-production cost under "other costs."

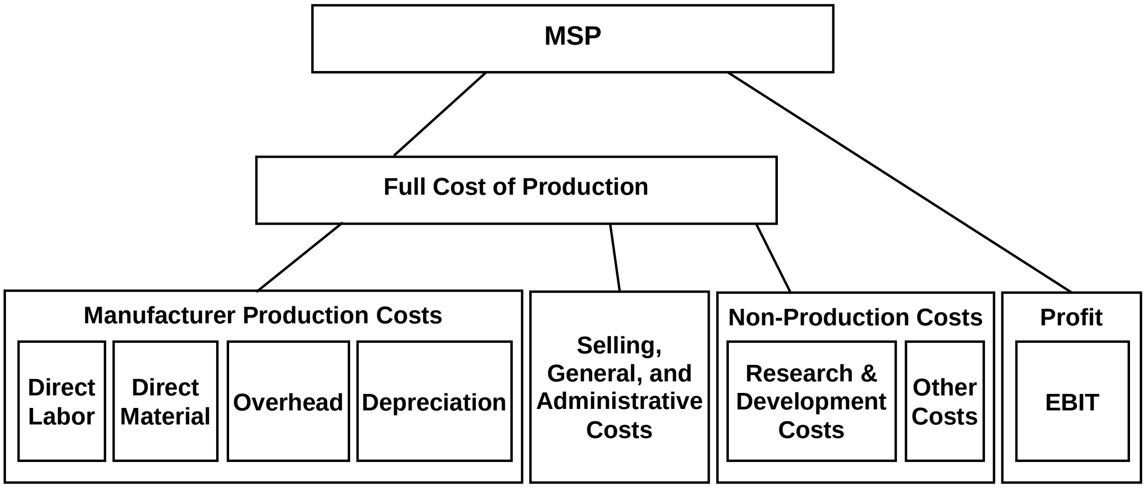

Figure 5.3.2 Components of Manufacturer Selling Price

5.4 ENERGY CONSUMPTION MODEL

The energy consumption model is the second of two key analytical models used in constructing cost-efficiency curves. This model estimates the energy consumption of envelopes and refrigeration systems of walk-in coolers and freezers at various performance levels using a design-options approach. DOE developed the energy consumption model as a Microsoft Excel spreadsheet.

For a given equipment class, the model estimates the energy consumption for the baseline and the energy consumption of several levels of performance above the baseline. The model calculates energy consumption at each performance level separately. For the baseline level, DOE calculated a corresponding MPC using the cost model (described in section 5.3 above). For each level above the baseline, DOE used the cost increases of the various design options to recalculate the MPC.

5.4.1 Screened-In Technologies

In the market and technology assessment (chapter 3 of the preliminary TSD), DOE defined an initial list of technologies that can be used to reduce the energy consumption of walk-in coolers and freezers. DOE then analyzed the following technology options:

5.4.1.1 Screened in Technologies for Envelopes

- Improved wall, ceiling, and floor insulation
- Improved door gaskets and panel interface systems
- Electronic lighting ballasts and high-efficiency lighting
- Occupancy sensors
- Automatic door opening and closing systems
- Air curtains
- Strip curtains
- Vestibule entryways

- Display and window glass system insulation performance
- Anti-sweat heater controls
- No anti-sweat systems

5.4.1.2 Screened in Technologies for Refrigeration Systems

- Ambient subcooling
- High-efficiency compressors (including scroll, 2-speed, and variable speed)
- Condenser coil
- Condenser fan motors
- Condenser fan blades
- Evaporator coil
- Evaporator fan blades
- Evaporator fan control
- Floating head pressure
- Defrost controls

5.4.2 Screened-In Technologies Not Considered in the Engineering Analysis

In the screening analysis (chapter 4 of the preliminary TSD), DOE narrowed this list by eliminating those technologies that can reduce annual energy consumption of walk-in coolers and freezers but do not reduce energy consumption as measured under the DOE test procedure. DOE then screened out those technologies that were not feasible, were not practical to manufacture, reduced equipment utility, or were considered unsafe.

The remaining list of screened-in technologies became an input to the engineering analysis. However, for reasons noted below, DOE did not incorporate all of these technologies in the energy consumption model. These include the following:

5.4.2.1 Ambient Subcooling

This process utilizes an oversized condenser or subcooling heat exchanger in order to further cool the condensed refrigerant. The result is a decrease in coolant enthalpy and an increase in specific capacity, meaning that a lower mass flow rate of compressed refrigerant, and thus less compressor power, is needed. Ambient subcooling is only needed when head pressure has been reduced to the lowest allowable value; in any other case, it is more efficient to simply reduce the head pressure. This system then proves effective when the ambient temperature is low enough that the head pressure must be kept at a high level, as is often the case for systems operating in cooler geographical regions.

DOE intends to include floating head pressure as a design option, as well as increasing the size of the condenser. This will have a similar effect to ambient subcooling, and as reducing the head pressure is more efficient, it was not necessary to implement ambient subcooling as a design option.

5.4.2.2 High Efficiency Two-speed and Variable-speed Compressors

Two- or multiple-capacity compressors present an opportunity for energy savings. These systems can take many forms, including single compressors with multiple stages or variable operating speeds as well as coupled sets of compressors which engage as necessitated by the load on the envelope. These technologies allow for the compressor operating time and power to more closely follow the heat load, resulting in improved performance and decreased energy consumption. This would save energy as measured by the test procedure, in reducing cyclic losses of the system. However, DOE's energy consumption model calculates the energy consumption analytically based on published data, and does not capture these cyclic losses. Also, DOE was unable to find published energy use data for two-speed and variable-speed compressors, so was unable to analytically determine the energy savings. Thus, DOE did not consider this option in the engineering analysis, but will consider this option in a future stage of the rulemaking if data are available.

5.4.3 Design Options

After conducting the screening analysis and removing from consideration those technologies described above, the following technologies were implemented as design options in the energy consumption model:

Envelope:

- Improved Wall, ceiling, and floor insulation
- Improved Door gaskets and panel interface systems
- Electronic lighting ballasts and high-efficiency lighting
- Occupancy sensors and automatic door opening and closing systems
- Air curtains and strip curtains
- Vestibule entryways
- Display and window glass system insulation enhancement
- Anti-sweat heater controls and no anti-sweat systems

Refrigeration:

- High-efficiency compressors
- Improved condenser coil
- High-efficiency condenser fan motors
- Improved condenser fan blades
- Improved evaporator coil
- Improved evaporator fan blades
- Evaporator fan controls
- Floating head pressure
- Defrost controls

Table 5.4.1 through Table 5.4.3 show the baseline options for each equipment class for envelope and refrigeration, respectively. Sections 5.4.4.1 through 5.4.5.8 contain details for the improved technologies.

Table 5.4.1 Baseline Design Options for Envelope, Non-Display

Design Options	ND.C. Small	ND.C. Medium	ND.C. Large	ND.F. Small	ND.F. Medium	ND.F. Large
Wall and Ceiling Insulation Thickness	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"
Floor Insulation Option	Baseline Floor	Baseline Floor	Baseline Floor	Baseline Floor	Baseline Floor	Baseline Floor
Insulation Materials A	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.
Insulation Materials B	None	None	None	None	None	None
Display Door Enhancement	-	-	-	-	-	-
Sealant Enhancement	Baseline Gasket	Baseline Gasket	Baseline Gasket	Baseline Gasket	Baseline Gasket	Baseline Gasket
Active Infiltration Reduction Devices	None	None	None	None	None	None
Passive Infiltration Reduction Devices	No Device	No Device	No Device	No Device	No Device	No Device
Door Systems	Baseline door closing mechanisms	Baseline door closing mechanisms	Baseline door closing mechanisms	Baseline door closing mechanisms	Baseline door closing mechanisms	Baseline door closing mechanisms
Anti-Sweat Heaters	-	-	-	-	-	-
Lighting: Display	-	-	-	-	-	-
Lighting: Non-Display	Compact Florescent Bulb	Compact Florescent Bulb	Compact Florescent Bulb	Compact Florescent Bulb	Compact Florescent Bulb	Compact Florescent Bulb
Additional Control System	No Control	No Control	No Control	No Control	No Control	No Control

Table 5.4.2 Baseline Design Options for Envelope, Display

Design Options	D.C. Small	D.C. Medium	D.C. Large	D.F. Small	D.F. Medium	D.F. Large
Wall and Ceiling Insulation Thickness	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"	Baseline Thickness, 4"
Floor Insulation Option	Baseline Floor	Baseline Floor	Baseline Floor	Baseline Floor	Baseline Floor	Baseline Floor
Insulation Materials A	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.	Baseline Insulation Material, XPS/PU Avg.
Insulation Materials B	None	None	None	None	None	None
Display Door Enhancement	Baseline Glass	Baseline Glass	Baseline Glass	Baseline Glass	Baseline Glass	Baseline Glass
Sealant Enhancement	Baseline Gasket	Baseline Gasket	Baseline Gasket	Baseline Gasket	Baseline Gasket	Baseline Gasket
Active Infiltration Reduction Devices	None	None	None	None	None	None
Passive Infiltration Reduction Devices	No Device	No Device	No Device	No Device	No Device	No Device
Door Systems	-	-	-	-	-	-
Anti-Sweat Heaters	No Controller	No Controller	Anti-Sweat Heater Controls	No Controller	No Controller	Anti-Sweat Heater Controls
Lighting: Display	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast
Lighting: Non-Display	-	-	-	-	-	-
Additional Control System	No Control	No Control	No Control	No Control	No Control	No Control

Table 5.4.3 Baseline Design Options for Refrigeration Systems

Design Option	**DC.M.I**	**DC.M.O**	**MC.M**	**DC.L.I**	**DC.L.O**	**MC.L**
Evaporator Coil	Standard Coil	Standard Coil	Standard Coil	Standard Coil	Standard Coil	Standard Coil
Evaporator Fan Motor Controllers	No Controls	No Controls	No Controls	No Controls	No Controls	No Controls
Evaporator Fan Blades	Standard Blades	Standard Blades	Standard Blades	Standard Blades	Standard Blades	Standard Blades
Condenser Coil for DC	Standard Coil	Standard Coil	-	Standard Coil	Standard Coil	-
Condenser Fan Motors for DC	Permanent Split Capacitor Motor	Permanent Split Capacitor Motor	-	Permanent Split Capacitor Motor	Permanent Split Capacitor Motor	-
Condenser Fan Blades for DC	Standard Blades	Standard Blades	-	Standard Blades	Standard Blades	-
Compressor Type for DC	Hermetic Compressor	Hermetic Compressor	-	Hermetic Compressor	Hermetic Compressor	-
Defrost Controls for XX.L	-	-	-	Timed Defrost	Timed Defrost	Timed Defrost
Floating Head Pressure DC.X.O	-	Fixed Head Pressure	-	-	Fixed Head Pressure	-

5.4.4 Details for Envelope Design Options

Table 5.4.4 summarizes the design option codes and descriptions for each envelope design option. Sections 5.4.4.1 through 5.4.4.8 contain details for improved technologies for envelopes.

Table 5.4.4 Design Option Codes and Descriptions for Envelopes

Design Option Code	Description
	Wall and Ceiling Insulation Thickness
TCK1	Baseline Thickness
TCK2	10% Thicker Insulation
TCK3	25% Thicker Insulation
TCK4	50% Thicker Insulation
TCK5	75% Thicker Insulation
	Floor Insulation Option
FLR1	Baseline Floor
FLR2	Cooler and Enhanced Freezer Floor
FLR3	Enhanced Floor
	Insulation Materials A
INS1	Baseline Insulation Material, XPS and PU
	Insulation Materials B
NONE	None
INSH1	Hybrid 1-VIP + INS1
VIP	Vacuum insulated Panel
	Display Door Enhancement
DR1	Baseline Glass
DR2	Enhanced 1
DR3	Enhanced 2
DR4	Superenhanced
	Sealant Enhancement
SE1	Baseline Gasket
XC	Extra Caulking
ATG	Advanced Tongue and Groove and Door Sweep
	Active Infiltration Reduction Devices
NOARD	None
AC	Air Curtain
	Passive Infiltration Reduction Devices
NOIRD	Baseline No Device
SC	Strip Curtain
	Door Systems
DRSTD	Baseline door closing mechanisms
VEST	Vestibule
	Anti-Sweat Heaters
ASHNC	Baseline (No Controller)
ASCTRL	Anti-Sweat Heater Controls
	Lighting: Display
T8	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast
LED	5 foot, LED
	Lighting: Non-Display
CFL	Compact Florescent Bulb
LED	LED Bulb
	Control System
CS1	Baseline No Control

CS2	Lighting Sensors
CS3	Lighting sensors and Door Opening Control

5.4.4.1 Improved Wall, Ceiling, and Floor Insulation

Wall and Ceiling Insulation Thickness

The thermal resistance of insulating materials increases approximately linearly with material thickness. Based on DOE's analysis and public comment, a typical WICF utilizes four inches of foam insulation in the walls and ceiling to slow the rate of heat conduction from the external environment to the internal cooled space of the walk-in. In addition, DOE found that many WICF manufacturers offer insulation in thicknesses of four, five and six inches.

Therefore, in the engineering analysis, DOE considered insulation thickness as one of the two independent variables that impacts full wall R-value. DOE assessed the incremental increase in cost due to additional material cost and separately evaluated the impact on shipping cost. Details of the analysis for material/labor and shipping cost are found in Table 5.4.5 through Table 5.4.8 below.

Table 5.4.5 Details for "Wall and Ceiling Insulation Thickness" Design Option

Code	Description	Thickness [inch]	Extra Material/Labor Cost [$/ft^2]
TCK1	Baseline Thickness	4.0	$ -
TCK2	10% Thicker Insulation	4.4	$ 0.220
TCK3	25% Thicker Insulation	5.0	$ 0.550
TCK4	50% Thicker Insulation	6.0	$ 1.130
TCK5	75% Thicker Insulation	7.0	$ 1.710

Table 5.4.6 Details for "Wall and Ceiling Insulation Thickness" Design Option Cont.

Thickness [in]	Calc. Type	Units	Calculation	Slope	Intercept
4	Weight	lbs	*Calculated*	1.884	311.040
5			*Calculated*	2.014	334.960
6			*Calculated*	2.198	322.190
4	Shipping Cost- Base	$	*Calculated*	0.353	-102.670
5			*Calculated*	0.353	-102.670
6			*Calculated*	0.353	-102.670
4	Shipping Cost- Fuel	$	*Calculated*	0.102	-76.074
5			*Calculated*	0.102	-76.074
6			*Calculated*	0.102	-76.074

Table 5.4.7 Details for "Wall and Ceiling Insulation Thickness" Design Option Cont.

	Total External Area	Thickness			
Input	*From Model*	*From Model*		**Slope**	**Intercept**
Output	**Weight**	*Interpolated*	lbs	*Calculated*	*Calculated*
	Base	*Interpolated*	$	*Calculated*	*Calculated*
	Fuel	*Interpolated*	$	*Calculated*	*Calculated*
	Total	*Interpolated*	$	*Calculated*	*Calculated*

Table 5.4.8 Total Shipping Cost for Product Classes and Thicknesses Considered

Design Option	**TCK1**	**TCK2**	**TCK3**	**TCK4**	**TCK5**
Wall Thickness [Inch]	4	4.4	5	6	7
ND.C. Small	$ 266.19	$ 277.26	$ 293.87	$ 321.56	$ 349.24
ND.C. Medium	$ 688.01	$ 713.19	$ 750.96	$ 813.91	$ 876.87
ND.C. Large	$1,729.36	$1,789.36	$1,879.38	$2,029.40	$2,179.42
D.C. Small	$ 130.69	$ 137.23	$ 147.05	$ 163.40	$ 179.76
D.C. Medium	$ 249.01	$ 259.51	$ 275.25	$ 301.50	$ 327.75
D.C. Large	$2,218.50	$2,294.87	$2,409.42	$2,600.34	$2,791.25
ND.F. Small	$ 228.52	$ 238.33	$ 253.06	$ 277.59	$ 302.13
ND.F. Medium	$ 741.70	$ 768.67	$ 809.14	$ 876.58	$ 944.02
ND.F. Large	$1,737.88	$1,798.17	$1,888.61	$2,039.34	$2,190.08
D.F. Small	$ 161.37	$ 168.94	$ 180.29	$ 199.21	$ 218.13
D.F. Medium	$ 309.85	$ 322.39	$ 341.19	$ 372.52	$ 403.86
D.F. Large	$3,241.10	$3,351.67	$3,517.52	$3,793.94	$4,070.35

DOE's analysis found that the incremental cost of manufacturing thicker products was dominated by material cost. The results of the analysis, for the various thicknesses, are shown in "Extra Material/Labor Cost" column of Table 5.4.5. The impact on shipping is a more complex calculation based on the final weight of a WICF product. The shipping weight is independently impacted by both the total surface area (or size) of a walk-in and selected insulation thickness. Then, the cost of shipping is dependent on a base charge (based on density and shipping class) and a fuel surcharge based on the distance shipped and weight.

Due to the multivariate nature of this calculation, best fit linear equations were first developed to calculate the weight of a given product based on its surface area and thickness (the slope and intercepts are shown in Table 5.4.6 above). Then using the calculated weight for a given thickness and area, the base and fuel cost of shipping could be developed. Finally, linear best fits of the shipping cost calculations were made as shown in Table 5.4.7. These last equations then allowed the model to interpolate the shipping cost based on any thickness ranging from two to seven inches in thickness. Table 5.4.8 shows the baseline calculations of shipping weight and cost for all product classes.

Floor Insulation

Since floor insulation is generally selected independently in standard WICF design practice, the floor insulation was treated as such in the engineering analysis. In addition, EPCA specified that insulated floors with a minimum of R-28 are required for walk-in freezers (not for coolers), requiring that freezers and coolers be treated differently. Therefore, DOE selected an uninsulated floor and four inches of insulation (approximately equivalent to R-28) for the baseline options for walk-in coolers and freezers respectively. Due to the inherently complex heat transfer physics of floor heat transfer, DOE developed finite element analysis (FEA) models to numerically solve for the average heat flux through the floor of WICF. The models used assumed design operating temperatures of -10 °F for freezers and 35 °F for coolers. The FEA results, for various floor sizes, are shown below in Table 5.4.9. FLR1 is the baseline option for both coolers and freezers while FLR2 and FLR3 reflect results of increasing thickness of insulation.

Table 5.4.9 Details for "Floor Insulation" Design Option, FEA Results

FEA Results		Average Heat Flux [Btu/h-ft^2]		
	Floor Area [ft^2]	FLR1	FLR2	FLR3
Cooler	36	8.61	1.48	1.21
	71.4	7.31	1.43	1.18
	80	6.9	1.41	1.17
	240	4.4	1.31	1.1
	750	2.97	1.13	0.97
	1200	3.04	1.18	1.01
Freezer	36	3.15	2.59	2.2
	48	3.11	2.56	2.18
	71.4	3.04	2.51	2.14
	180	2.88	2.4	2.06
	500	2.54	2.16	1.88
	1200	2.51	2.14	1.86

Table 5.4.10 shows the design option inputs used to complete the FEA simulations:

Table 5.4.10 Details for "Floor Insulation" Design Option, FEA Inputs

Code	Description	Thickness Cooler	Thickness Freezer	R-value Cooler	R-value Freezer
FLR1	Baseline Floor	0	4	0.0	22.42
FLR2	Cooler and Enhanced Freezer Floor	4.00	5.00	22.42	28.03
FLR3	Enhanced Floor	5.00	6.00	28.03	33.64

Floor construction, when a WICF manufacturer provides the floor, is similar to the typical WICF wall panel construction. Therefore, the same cost model for WICF wall panels was used to calculate the incremental cost increase for each design option. The results used in the engineering analysis are shown in Table 5.4.11.

Table 5.4.11 Details for "Floor Insulation" Design Option, Cost

Code	Normalized Insulation Cost [$/ft2] Cooler	Normalized Insulation Cost [$/ft2] Freezer
FLR1	$0.00	$6.66
FLR2	$6.66	$7.23
FLR3	$7.23	$7.88

Insulation Materials A

Based on DOE analysis and stakeholder comments, DOE concluded that WICF manufacturers almost exclusively currently use one of two foam insulation types: board stock extruded polystyrene (XPS) or foam-in-place polyurethane (PU)[iii]. The thermal resistance performance characteristics of each product type are quite similar, as well as the total cost associated with a given material. Therefore, DOE averaged the material properties for the baseline design option as shown in Table 5.4.12. This represents the second of the two independent variables that impact full wall R-value (insulation thickness, the first, was described earlier). Since foam materials were considered the baseline option, foam materials are considered to have zero cost when compared to additional material options.

Table 5.4.12 Details for "Insulation Materials A" Design Option

Code	Description	R-value/inch composite
INS1	Baseline Insulation Material, XPS and PU	5.902

Insulation Materials B

DOE found that several other insulating materials or systems are commercially available but have limited market penetration. These include, but are not limited to, vacuum insulated panels (VIPs), aerogel materials, and hybrids of these and traditional foam materials. In order to account for these high R-value (and generally high cost) alternatives, DOE incorporated these options into the engineering analysis. The cost and performance data are based on discussions with manufacturers and DOE internal analysis. DOE estimated that the cost of R-10/inch aerogel was $8.00-$13.00 or approximately $1.00/[ft^2-F-h/Btu/inch]. DOE found that thin VIPs encased in standard foam (represented by INSH1) and VIPs alone have $/[$ft^2$-F-h/Btu/inch]ratios of approximately $0.10 and $0.13 respectively. For comparison, DOE estimates that standard foam such as XPS or PU has a cost-performance ratio of $0.02 /$/[ft^2-F-h/Btu/inch]. DOE concluded that at current market price and performance per inch, aerogel products are not a viable alternative to VIPs for use in walk-in coolers and freezers and therefore were not included in the engineering analysis.

Table 5.4.13 Details for "Insulation Materials B" Design Option

Code	Description	Wall Thickness %	Wall Thickness %	Full Thickness [inch]
NONE	None			
INSH1	Hybrid 1-VIP + INS1	75%	25%	2
VIP	Vacuum Insulated Panel	100%	0%	2

Table 5.4.14 Details for "Insulation Materials B" Design Option, Continued

Code	Other Insulation Cost [$/brd-ft]	Foam Insulation Cost [$/brd-ft]	Insulation Cost [$/ft^2] @ 2" Thickness composite	Other R-value/ inch	Foam R-value /inch	R-value /inch composite	R-value composite @ Full Thickness
NONE	-	-	-	-	-	-	-
INSH1	$3.88	$0.40	$6.02	37.00	5.90	29.15	58.30
VIP	$4.70	$0.00	$9.40	37.00	37.00	37.00	74.00

In order for a manufacturer to incorporate these advanced insulating materials, significant engineering and tooling costs would be incurred. These costs are amortized over the life of the equipment and divided by the assumed annual unit production. The result is levelized cost per square foot of WICF panel produced. These assumptions and calculations are shown in Table 5.4.15 and Table 5.4.16 below.

Table 5.4.15 Details for "Insulation Materials B" Design Option, Engineering Cost

Engineering Costs		
Design Option	**INSH1**	**VIP**
Description	**Hybrid 1-VIP + INS1**	**Vacuum Insulated Panel**
Assumed costs to design system, manufacturing process, and tooling	$ 200,000.00	$ 500,000.00
New Equipment Cost	$ 150,000.00	$ 300,000.00
Design Lifetime [Years]	7	7
Units per Year [unit = ft2]	11,200,000	11,200,000
Cost Per Unit [ft2]*	$ 0.004	$ 0.010
*Assuming 4' X 8' panel		

Table 5.4.16 Details for "Insulation Materials B" Labor Cost

Labor Costs		
Item	**Hybrid 1-VIP + INS1**	**Vacuum Insulated Panel**
Additional Labor [minutes/per panel]	10	15
Labor Rate [$/Hr]	$ 24.00	$ 24.00
Cost Per Unit [ft2]	$ 0.13	$ 0.19

5.4.4.2 Improved Door Gaskets and Panel Interface Systems

Sealant Enhancement

The main pathway for air exchange during steady-state operation of WICF is through the panel-to-panel interfaces and door gaskets. In particular, non-display type doors that utilize door sweeps are prone to slight air leakage. Typical WICF construction consists of a cam-lock system that squeezes neighboring panels together. This provides a compression force on gaskets that are normally placed between the panels, creating a reasonably well sealed interface. DOE considered this type of construction the baseline option in the engineering analysis. However, additional designs exist that utilize tongue-and-groove construction (see Figure 5.4.1 below) and novel locking systems that further reduce air exchange. In addition, simply adding additional sealant to the panel-to-panel and panel-to-floor interface may reduce air infiltration. Both the advanced and simple improvements are reflected in Advanced Tongue and Groove (ATG) and Extra Caulking (XC) and design options in the engineering analysis.

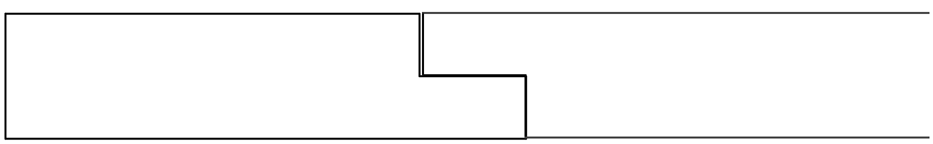

Figure 5.4.1 Panel Tongue and Groove Construction

DOE research found that advanced tongue and groove design is capable of reducing infiltration rates to at least 0.06 $ft^3/h\text{-}ft^2$ (flow rate per unit of external surface area). The resulting calculations for each product class and analysis point are shown in Table 5.4.17 and Table 5.4.18 below. Advanced tongue-and-groove design was considered the max-tech option, and the corresponding infiltration rate was used to reverse calculate the performance of the previous design options in the engineering analysis. DOE estimated that about one third of the total steady-state infiltration was caused by losses through the door sweep of non-display WICF passage doors.

Table 5.4.17 Details for "Sealant Enhancement" Design Option

Code	Description	Material [$/ft2] or [$/lin-ft]
SE1	Baseline Gasket	$ -
XC	Extra Caulking	$ 0.09
ATG	Advanced Tongue and Groove and Door Sweep	$ 1.23

Table 5.4.18 Details for "Sealant Enhancement" Design Option, Cont.

	Total External Surface Area	Display Doors	Passage Doors	Freight Doors	SE1	XC	ATG
Units	ft^2	-			ft^3/h		
ND.C. Small	433	0	1	0	56	50	28
ND.C. Medium	1088	0	1	1	141	125	70
ND.C. Large	2820	0	2	1	487	447	218
D.C. Small	230	3	1	0	30	26	15
D.C. Medium	404	8	1	0	52	47	26
D.C. Large	3844	50	2	0	664	609	297
ND.F. Small	309	0	1	0	40	36	20
ND.F. Medium	911	0	1	1	118	105	59
ND.F. Large	2080	0	2	1	359	329	161
D.F. Small	230	3	1	0	30	26	15
D.F. Medium	404	8	1	0	52	47	26
D.F. Large	3844	50	2	0	664	609	297

The assumptions used to calculate the incremental cost associated with each design option are shown in Table 5.4.19 through Table 5.4.21 below.

Table 5.4.19 Details for "Sealant Enhancement" Design Option, Engineering Cost

Engineering Costs	Advanced Tongue and Groove	Advanced Door Sweep
Item	**Value**	**Value**
Assumed costs to design system, manufacturing process, and tooling	$ 100,000.00	$ 80,000.00
New Equipment Cost	$ 50,000.00	$ 25,000.00
Design Lifetime [Years]	7	7
Units per Year [unit = ft^2]	11200000	14400
Cost Per Unit	$ 0.002	$ 1.042

Table 5.4.20 Details for "Sealant Enhancement" Design Option, Labor Cost

Labor Costs	Advanced Tongue and Groove	Advanced Door Sweep
Item	**Value**	**Value**
Additional Labor [minutes]	5	10
Labor Rate [$/h]	$ 24.00	$ 24.00
Cost Per Unit	$ 0.06	$ 0.13

Table 5.4.21 Details for "Sealant Enhancement" Design Option, Material Cost

Caulking Assumptions	
Item	**Value**
Tube Size [Fluid Oz]	10
Tube Cost [$]	$ 4.00
Cross-sectional Area of Bead [$inch^2$]	0.0351
Volume of Caulk [Fl Oz/Lin-ft]	0.233
Linear Feet per Tube	42.85
Cost per Linear Foot	$ 0.09

5.4.4.3 Electronic Lighting Ballasts and High-Efficiency Lighting

Since the associated lighting systems for display and non-display type WICF are quite different, DOE split the lighting engineering analysis by the display and non-display characteristic. This helped simplify the model calculations and provides more clarity on design options used.

Lighting: Display

EPCA specified minimum efficacy of 40 lumens/W, including ballast losses, for all lights. (42 U.S.C. 6313(f)(1)(G) Therefore, DOE did not consider any lighting systems that did not meet this limit. In addition, DOE analysis indicated that the lighting industry had mostly shifted to high efficiency, electronic ballasted lighting systems. DOE also noted that a number of display door manufacturers have eliminated the use of florescent systems and now use LED lighting systems as their baseline option. DOE is considering the use of LEDs as the baseline option but completed the preliminary engineering analysis using T8 bulbs with electronic ballasts as the baseline option. The associated performance and cost data used in the model are shown in Table 5.4.22 through Table 5.4.25 below.

Table 5.4.22 Details for "Lighting: Display" Design Option, Performance Data

Code	Description	Lamp Power [W/bulb]	Ballast Power [W/bulb]
T8	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	54.5	3.5
LED	5 foot, LED	16.1	0.0

Table 5.4.23 Details for "Lighting: Display" Design Option, Performance Data Cont.

	Lamp			Ballast			System	
Code	**Type**	**Rated Power [W]**	**Rated Lumens**	**Number of Lamps**	**Ballast Factor**	**Total Input Power [W]**	**Efficacy [LPW]**	**Light Output [Lumens]**
T8	F32T8/HL	58.0	3100	1	0.94	58.0	50.2	2914.0
LED	-	16.1	1342	1	1.00	16.1	53.9	1342.0

Table 5.4.24 Details for "Lighting: Display" Design Option, Cost Data

		Cost		
Code	**Description**	**Lamp**	**Ballast**	**Total**
T8	5 foot, T8 Electronic, Normal Lumen Blub, Normal BF Electronic Ballast	$10.99	$14.00	$24.99
LED	5 foot, LED	$115.00	-	$115.00

Table 5.4.25 Details for "Lighting: Display" Design Option, Cost Data Cont

Description	**Avg. OEM Price**
120-277V Electronic Ballast T8 lamps (-20F starting capability)	$14.00
Description	**Average Wholesale Price**
5' 58W T8 low-temp lamp	$10.99
LED System Cost Estimate	**Value**
LED power use, 1-row 5' fixture [W]	16.1
Average OEM Cost of 1-row 5' LED fixture	$115.00

Lighting: Non-Display

As for display type walk-ins, DOE only considered design options with at least 40 lumens/W efficacy for non-display WICF. The two readily available technologies that meet this standard are light emitting diode (LED) bulbs and compact florescent light (CFL) bulbs. LED bulbs are higher performing and significantly more expensive than CFLs, therefore DOE selected CFLs as the baseline design option for non-display systems. The data used for calculations in the engineering analysis are shown in Table 5.4.26.

Table 5.4.26 Details for "Lighting: Non-Display" Design Option

Code	Description	Bulb Power [W/bulb]	Ballast Power	Bulb Cost [$]	Rated Power [W]	Rated Lumens	Efficacy [L/W]
CFL	Compact Florescent Bulb	13.0	2.0	$1.50	15.0	825.0	55.0
LED	LED Bulb	7.0	-	$35.00	7.0	450	64.3

5.4.4.4 Occupancy Sensors and Automatic Door Opening and Closing Systems

Control Systems

DOE reviewed a number of control system related design options. While most control systems are designed to intelligently control the refrigeration equipment, there are a number of available features that are relevant to the envelope only. DOE found that most WICF manufacturers offer control systems but that there was limited end-user demand or market penetration. The exception was for anti-sweat heater controllers, which will be discussed in another section. Therefore, DOE considered the baseline design option to be a WICF without any type of control features, CS1.

The next design option (CS2) DOE considered is occupancy sensors to control lights. This allows for "on demand" use of lights and helps prevent accidental wasted energy. As described in the proposed WICF test procedure, DOE recognizes that actual energy use will vary based on specific walk-in use or type. 75 FR 199. Therefore, the engineering analysis adopts the same assumption for percent time off (PTO) of devices that are regulated by control systems. The assumptions used in the analysis can be found in Table 5.4.27. The last option, CS3, incorporates the use of an automatic door opening and closing sensor. Using the same methodology in the WICF test procedure, the use of the automatic door devices is assumed to reduce the average time that a door remains open during each opening event. This reduces direct air infiltration through the door and corresponding energy use by the refrigeration equipment.

Table 5.4.27 Details for "Control Systems" Design Option

Code	Description	PTO Lights	Automatic Door Open/Close	PTO Other	Cost
CS1	Baseline No Control	25%	NO	0%	$ -
CS2	Lighting Sensors	50%	NO	0%	$ 250.00
CS3	Lighting sensors and Door Opening Control	50%	YES	25%	$ 450.00

The cost estimates used for the various control system options were developed based on component and WICF manufacturer comments.

5.4.4.5 Air Curtains and Strip Curtains

Active Infiltration Reduction Devices

Active infiltration reduction devices (AIRDs), such as an air curtain, are devices that reduce air infiltration through open doorways that consume energy in order to function. While both passive and active devices serve the same purpose, DOE considered it important to classify them differently. AIRDs' cost benefit ratio (and associated payback period) is dependent on the ratio of energy saved versus the energy used to operate the device rather than simply the energy saved for passive devices. In addition, active devices needed to be considered independently of passive devices as it is possible for these devices to be installed simultaneously in an actual walk-in. For example, strip curtains can serve as the primary method to reduce air exchange while an air curtain can act as a secondary reduction method.

DOE considered air curtains as the only viable AIRD for walk-ins. The performance of these devices is normally measured in terms of effectiveness. An effectiveness of 1.0 corresponds to a device that prevents 100% of air exchange from occurring when a door is open. Conversely, an effectiveness of zero means that the device does not reduce air exchange by a measureable amount. DOE assumed that the effectiveness of an air curtain, based on extensively cited ASHRAE research[iv], is 0.8.

There is limited market penetration of air curtains, particularly for smaller sized WICF. Therefore, DOE selected a system without an air curtain for the baseline option.

Table 5.4.28 Details for "Active Infiltration Reduction Devices" Design Option

Code	Description	Effectiveness	$/door	Rated Power [W]
NOARD	None	0.00	$ -	
AC	Air Curtain	0.80	$ 460.00	500.00

Passive Infiltration Reduction Devices

Strip curtains are the most widely used passive infiltration reduction devices (PIRDs) in WICF today. In addition, EPCA cites strip curtains as one "method of minimizing infiltration when doors are open." However, DOE research found that throughout the industry there is limited preference to use vertically hung strip curtains in walk-ins. End-users complain that the vinyl strips are a nuisance because the strips brush against personnel's faces and heads as they pass through the door. Therefore, WICF manufacturers typically select other methods to maintain EPCA compliance, such as spring hinged doors.

Another option DOE considered was impact doors. These have been shown to have nearly identical effectiveness as strip curtains and are equally if not more transparent than strip curtains. Impact doors are generally constructed of two large overlapping transparent plastic flaps that are connected to the door frame using bi-directional hinges. After pushing through the flaps, the spring hinges swing the two flaps back into place to reduce air exchange. Since the flaps open to the sides, rather than being vertically hung like strip curtains, the material does not drag over the face or arms of personnel passing through the doorway. DOE has found that this is an important feature when considering end-user adoption.

However, impact doors are nearly twice as costly as strip curtains. While impact doors appear to be a practical alternative, the design options must be ordered such that the first option has the shortest payback period and the last has the longest payback. If the options do not follow this order then the engineering analysis produces nonsensical results. Compared to strip curtains, impact doors always have a higher cost but identical performance and therefore always have a longer payback period. Both because of the longer payback period and that the options have the same effectiveness, impact doors would never be selected in the model. For these reasons, DOE only considered strip curtains as a design option for PIRD.

The assumed strip curtain effectiveness and cost estimates are shown in Table 5.4.29 below. Strip curtains used for freezers must rely on materials that do not become brittle and/or fracture at low temperatures. Therefore, freezer strip curtains are typically more expensive than cooler strip curtains as shown in Table 5.4.29.

Table 5.4.29 Details for "Passive Infiltration Reduction Devices" Design Option

			Cooler	**Freezer**
Code	**Description**	**Effectiveness**	**Cost [$/ft2]**	**Cost [$/ft2]**
NOIRD	Baseline No Device	0.00	$ -	$ -
SC	Strip Curtain	0.90[v]	$ 4.33	$ 5.28

5.4.4.6 Vestibule Entryways

Door Systems

In addition to passive and active IRDs, DOE considered unique walk-in designs that could reduce the amount of air infiltration during door opening events. As described in Chapter 4 revolving door systems were not considered in the engineering analysis due to impact on utility of the WICF. However, unlike revolving doors, vestibule entry ways are occasionally used for walk-ins. These entry ways are very effective at reducing direct air exchange. When the primary door is accessed the secondary door remains closed (see Figure 5.4.2). When the secondary door opens, the primary has already closed, substantially reducing air movement. In the engineering analysis, DOE created a design option that incorporates this design as shown in Table 5.4.30 below. For the cost and effectiveness, DOE only considered designs that utilized a standard WICF insulated hinged door as the primary and the secondary doors. Variations such as the primary or secondary entry way only protected by an air or strip curtain were not considered. The cost also includes the expense of additional wall panels that would be required to enclose the intermediate space between the primary and secondary entry-ways.

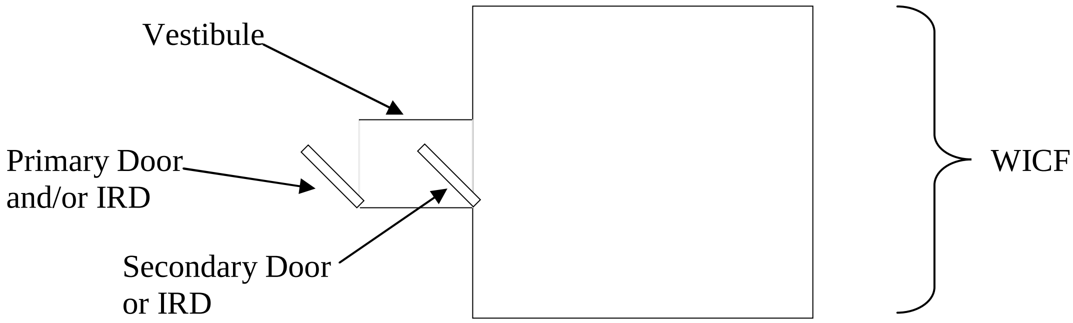

Figure 5.4.2 Overhead View of Walk-In and Vestibule Entryway

Table 5.4.30 Details for "Door Systems" Design Option

Code	Description	Effectiveness	$/system
DRSTD	None	0.00	$ -
VEST	Vestibule	0.98[vi]	$1,000.00

5.4.4.7 Display and Window Glass System Insulation Enhancement

Display Door Enhancement

Heat conduction through glass display doors is one of the largest energy loss components of a walk-in. The heat that is transferred though the doors is primarily dependent on the door frame material and insulation, the number and spacing of glass panes, the type of inert gas fill and the use of various low-emissivity coatings. DOE found that typical display doors use vinyl composite frames and argon gas fill. EPCA specified that, at a minimum, cooler and freezers display doors must utilize two and three pane doors respectively. Therefore, DOE selected these characteristics for the baseline options for coolers and freezers as show in Table 5.4.33 and Table 5.4.34 below. Starting from this baseline DOE then considered additional design options DR2, DR3 and DR4. DR2 reflects the display door characteristics widely available for high performance display doors. DR3 and DR4 which incorporate multiple panes, additional coatings and higher performing gas fill corresponding to the mid and maximum performance technologies available.

Table 5.4.31 Details for "Display Door Enhancement" Design Option

		Cooler	Freezer	Cooler	Freezer
Code	**Description**	**Overall U-Factor at 75 F [Btu/hr-f-F]**	**Overall U-Factor at 75 F [Btu/hr-f-F]**	**Cost [$/ft^2]**	**Cost [$/ft^2]**
DR1	Baseline Glass	0.432	0.303	$64.29	$71.43
DR2	Enhanced 1	0.269	0.262	$88.93	$90.82
DR3	Enhanced 2	0.123	0.123	$112.97	$129.39
DR4	Superenhanced	0.080	0.080	$146.18	$155.21

Due to limited availability of component manufacturer thermal performance data, DOE predicted the performance of the various design options using Lawrence Berkeley National Lab's (LBNL) Window 5.2 program. As specified in the WICF test procedure NOPR, this is a widely used and verified tool for calculating performance of glass doors. 75 FR 186. The key assumptions, shown in Table 5.4.32, were used to generate the performance data shown in Table 5.4.31. The predicted U-value from Window 5.2 is a full door system prediction including the center of glass, door frame etc.

Table 5.4.32 Details for "Display Door Enhancement" Design Option, Window 5.2

Assumptions used in Window 5.2 calculations:
• Clear glass is 0.125" thick
• Low-E glass is 0.125" thick clear glass with low-E coating (emissivity=0.54)
• 0.5" thick gas layer for Argon, 0.3" for Krypton/Xenon
• 100% purity gas filled windows
• R-value of full thickness frame = 2.15 ft2-F-h/Btu
Source: LBNL WINDOW 5.2 Software

Table 5.4.33 Details for "Display Door Enhancement" Design Option, Window 5.2, Coolers

Coolers	Frame	Number of Panes	Glass type: Pane 1	Glass type: Pane 2	Glass type: Pane 3	Glass type: Pane 4	Gas Fill
Baseline	**Vinyl/Composite**	2	Clear	Clear	-	-	Argon
Enhanced 1	**Vinyl/Composite**	3	Low-E	Clear	Low-E	-	Argon
Enhanced 2	**Vinyl/Composite**	4	Low-E	Clear	Clear	Low-E	Krypton
Superenhanced	**Vinyl/Composite**	4	Low-E	Low-E	Low-E	Low-E	Xenon

Table 5.4.34 Details for "Display Door Enhancement" Design Option, Window 5.2, Freezers

Freezers	Frame	Number of Panes	Glass type: Pane 1	Glass type: Pane 2	Glass type: Pane 3	Glass type: Pane 4	Gas Fill
Baseline	**Vinyl/Composite**	3	Clear	Clear	Clear	-	Argon
Enhanced 1	**Vinyl/Composite**	3	Low-E	Clear	Low-E	-	Krypton
Enhanced 2	**Vinyl/Composite**	4	Low-E	Clear	Clear	Low-E	Krypton
Superenhanced	**Vinyl/Composite**	4	Low-E	Low-E	Low-E	Low-E	Xenon

Table 5.4.35 Details for "Display Door Enhancement" Design Option, Gas Fill Cost

Incremental Cost of Krypton and Xenon		
Take Size (liquid)	64	Liters
Cost Per Liter	$23.00	$/Liter
Cost Per Tank	$1,472.00	$/Tank
Pressure	2300	PSI
Expanded Volume	10014	Liters
Cost Per Liter (expanded)	$ 0.15	$/Liter
Liters Per Gap	10.36	Liters
Cost Per Gap	$1.52	$
Krypton, Cost Per ft2	$0.11	$
Xenon, Cost Per ft2	$0.21	$
Source: Discussion with wholesale gas companies		

5.4.4.8 Anti-sweat Heater Controls and No Anti-sweat Systems

Anti-Sweat Heaters

The external surface of glass display doors typically cool to temperatures below the dew point of the surrounding air. When this occurs, condensate or "sweat" begins to form on the exposed surface of the glass. It first appears as a fog, and if left unchecked, further condenses to droplets large enough to begin to roll and drip off the surface. The amount and rate of sweating is dependent on the relative humidity surrounding the walk-in and the temperature of the glass. In order to ensure the temperature of the glass stays above the dew point of the surroundings, electric resistive heater wire is installed around the frame of the door. Typical systems, regardless of the relative humidity, continuously power the heater wire. This means that for a large portion of time, the door glass is heated to temperatures far higher than necessary to remain above the dew point, resulting in additional electricity consumption.

With the use of an anti-sweat heater control system that senses the relative humidity, the level of heating required to avoid condensate can be precisely matched to the conditions. The energy savings seen in practice for freezers and coolers is approximately 50 percent and 75 percent, respectively.

Therefore, DOE set the baseline option of display walk-ins to not include anti-sweat heaters and the next design option, ASCTRL, to include their use. Since freezers operate at much colder temperatures than coolers, the wattage required for freezer heater wire is higher to ensure the appropriate door temperature is achieved. See Table 5.4.36 for details.

In recent years the cost of anti-sweat controls has dropped significantly. A number of display door manufacturers now offer the controls as a standard option. A single $100 controller is capable of controlling up to five doors, so the average cost on a per door basis is approximately $20.00[vii].

As described above, sweating is a function of glass temperature and the dew point (or relative humidity) of the surrounding air. The external surface of the glass experiences such low temperatures because of the low resistivity of most glass doors. However, as the thermal resistance to heat transfer of the glass door increases, the glass surface temperature also increases. Therefore, if the glass door has high enough thermal resistivity it is possible to reduce or entirely eliminate the need for anti-sweat heaters. Based on manufacturer comment, DOE estimated that with display door option DR2, the power for heater wire could be reduced to 1W/ft and for DR3 or DR4, the heater wire could be eliminated.

Table 5.4.36 Details for "Anti-Sweat Heaters" Design Option

		Cooler	Freezer	Heater wire		
Code	**Description**	**Passage Door Wire [W/ft]**	**Passage Door Wire [W/ft]**	**PTO Cooler**	**PTO Freezer**	**Cost**
ASHNC	Baseline (No Controller)	5.40	8.00	0%	0%	$-
ASCTRL	Anti-Sweat Heater Controls	5.40	8.00	75%	50%	$100.00

5.4.5 Details for Refrigeration System Design Options

Table 5.4.37 summarizes the design option codes and descriptions for each refrigeration system design option. Sections 5.4.5.1 through 5.4.5.8 contain details for improved technologies for refrigeration systems.

Table 5.4.37 Design Option Codes and Descriptions for Refrigeration Systems

Design Option Code	Description
	High-Efficiency Scroll Compressors
HER	Hermetic Compressor
SCR	Scroll Compressor
	Condenser Coil
CD1	Baseline Coil
CD2	Larger Coil
	Condenser Fan Motors
PSC	Permanent Split Capacitor Motors
ECM	Electronically Commutated Motors
	Evaporator Fan Blades
EB1	Standard Evaporator Fan Blades
EB2	Improved Evaporator Fan Blades
	Condenser Fan Blades
CD1	Standard Condenser Fan Blades
CD2	Improved Condenser Fan Blades
	Evaporator Coil
EV1	Baseline Coil
EV2	Larger Coil
	Evaporator Fan Control
EM1	Baseline (No Control)
EM2	Evaporator Fan Control
	Floating Head Pressure
-	Baseline (Fixed Head Pressure)
FHP	Floating Head Pressure
	Defrost Controls
DF1	Baseline (Timed Defrost)
DF2	Defrost Control

5.4.5.1 High-Efficiency Scroll Compressors

The compressor design option applies only to DC equipment classes. In consultation with compressor manufacturers and external design experts, DOE determined that two levels of technology were applicable for the compressor design option. The minimum technology level is a standard single-speed hermetic compressor, and the maximum technology level is a scroll compressor. (See section 5.4.2.2 for why two-speed and variable-speed compressors were not considered.) Reductions in total system energy consumption are realized through a reduction in compressor energy consumption.

DOE collected performance data for single-speed hermetic compressors and scroll compressors over a range of capacities applicable to the covered equipment. DOE then selected one representative hermetic compressor and one representative scroll compressor for two different sizes of each equipment class, representing two analytical points for a small and a large unit of each class. The performance data were then used to calculate the power and capacity of the compressors using the 10-coefficient method described in section 5.4.9.1.

Table 5.4.38 Details for "High-Efficiency Scroll Compressor" Design Option

Class	Baseline (Hermetic) Model	High Efficiency (Scroll) Model
DC.M.I – Small	CS10K6E-PFV	ZB10KCE-PFV
DC.M.I – Large	CS18K6E-PFV	ZB19KQE-PFV
DC.M.O – Small	CS12K6E-PFV	ZX15KCE-PFV
DC.M.O – Large	CS18K6E-PFV	ZX21KCE-PFV
DC.L.I – Small	CF06K6E-PFV	ZF06K4E-PFV
DC.L.I – Large	CF12K6E-PFV	ZF11K4E-PFV
DC.L.O – Small	CF06K6E-PFV	ZF06K4E-PFV
DC.L.O – Large	CF12K6E-PFV	ZF11K4E-PFV

5.4.5.2 Condenser Coil

This design option applies only to DC equipment classes. DOE considered two technology levels: a standard coil and a larger coil that was sized to run at a saturated condensing temperature (SCT) that is cooler than that of the baseline coil. DOE calculated the temperature difference (TD) between the SCT and the ambient temperature, for the baseline coil. Then DOE considered a theoretical improved coil that ran at an SCT such that the TD was half that of a baseline coil. DOE chose a multiplier rather than a constant decrease because some classes of equipment, such as low temperature equipment, are already set to run at a smaller TD on the condenser. Furthermore, there are heat transfer constraints on how far the TD can be decreased. DOE then calculated the size of the improved coil from the baseline coil, assuming all other characteristics stayed the same, by using the heat transfer equation:

$$A = \frac{\dot{Q}}{U \times TD} \qquad \textbf{Eq. 5.1}$$

where:
A = face area of the coil;
$\dot{Q}$ = rate of heat transfer;
U = constant coil coefficient
TD = temperature difference

Thus, a smaller TD necessitates a larger area. DOE calculated the new area assuming that both the length and the width of the coil would change at the same rate. DOE then used the cost model to calculate the added cost of materials to produce the larger coil. Because compressor capacity and power consumption are directly related to SCT, reductions in the energy consumption are realized through an improved normalized energy consumption. Details of the TD multiplier are shown in Table 5.4.39.

Table 5.4.39 Details for "Condenser Coil" Design Option

Code	Description	TD Multiplier
CD1	Baseline	1
CD2	Improved	0.5

For improved condenser coils, DOE assessed the incremental increase in cost due to additional material cost and separately evaluated the impact on shipping cost for each dedicated condensing equipment class and size. The results are shown in Table 5.4.40.

Table 5.4.40 Details for "Condenser Coil" Design Option, Continued

Equipment Class	Extra Material/Labor Cost ($)	Extra Shipping Cost ($)
DC.M.I – Small	$75.77	$12.66
DC.M.I – Large	$147.32	$28.33
DC.M.O – Small	$191.22	$28.44
DC.M.O – Large	$190.80	$28.33
DC.L.I – Small	$96.40	$12.74
DC.L.I – Large	$155.99	$30.63
DC.L.O – Small	$116.59	$12.74
DC.L.O – Large	$202.33	$30.63

5.4.5.3 Condenser Fan Motors

In conjunction with fan blades, condenser fan motors are necessary for transferring heat from the refrigerant into the ambient air. The condenser fan motor design option applies only to the dedicated condensing equipment classes. EPCA requires that all condenser fan motors under 1 horsepower be either ECMs (brushless DC motors), PSCs, or 3-phase. (42 U.S.C. 6313(f)(1)(F)) Currently, DOE considers PSC motors as the minimum technology and ECMs as the maximum technology. DOE did not consider 3-phase motors in the engineering analysis as discussed in chapter 4 of the preliminary TSD.

Error! Reference source not found. Table 5.4.41shows details for the condenser fan motor design option. The motor efficiency levels listed were taken from American National Standards Institute (ANSI)/ARI Standard 1200-2006, "Performance Rating of Commercial Refrigerated Display Merchandisers and Storage Cabinets," as DOE assumed that these types of motors were similar in efficiency. Because condenser fan motors are outside the refrigerated space, efficiency improvements only impact the direct electrical consumption of the motors and not the heat load.

Table 5.4.41 Details for "Condenser Fan Motor" Design Option

Code	Description	Rated Power (HP)	Actual Power (W)	Efficiency	Cost
PSC	Permanent Split Capacitor	1/6	428	29%	$35.58
ECM	Brushless DC Motor	1/6	188	66%	$71.29

5.4.5.4 Evaporator and Condenser Fan Blades

High efficiency fan blades reduce motor shaft power requirements by moving air more efficiently. Most evaporator and condenser fans use stamped sheet metal or plastic axial fan blades that are paddle-shaped. These fan blades are lightweight and inexpensive. The blades are typically supplied by a fan blade manufacturer and mounted to the motor by the equipment manufacturer. The higher efficiency blades DOE considered typically have swept fins for improved airflow. DOE estimated that these fan blades could increase fan efficiency by 15 percent for the evaporator and condenser fans. This efficiency improvement is realized as lower energy consumption by the fan motor.

Figure 5.4.3 Examples of Standard Fan Blades[viii], [ix]

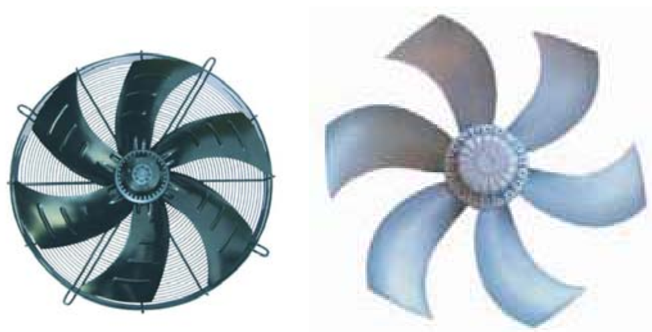

Figure 5.4.4 Examples of High Efficiency Fan Blades[x], [xi]

Table 5.4.42 Details for "High Efficiency Fan Blades – Evaporator" Design Option

Code	Description	Fan Power Multiplier	Cost Premium per Fan
EB1	Baseline	1	$-
EB2	Improved	0.85	$28.01

Table 5.4.43 Details for "High Efficiency Fan Blades – Condenser" Design Option

Code	Description	Fan Power Multiplier	Cost Premium per Fan
CB1	Baseline	1	$-
CB2	Improved	0.85	$18.27

5.4.5.5 Evaporator Coil

Similar to the condenser coil, DOE considered two technology levels for the evaporator: a standard coil and a larger coil that was sized to run at a saturated evaporator temperature (SET) (also known as saturated suction temperature, or SST) that is warmer than that of the baseline coil. DOE calculated the temperature difference (TD) between the SET and the walk-in's interior temperature, for the baseline coil. Then DOE considered a theoretical improved coil that ran at an SET that was 2 degrees warmer than that of a baseline coil. DOE chose a relatively small change in SET because the TD can drastically affect the humidity inside the walk-in. This could result in a decrease in utility for some walk-ins because of the nature of the product stored. For instance, fruits and flowers must be stored at a certain humidity in order to keep them fresh and not overdry them. In consultation with experts, DOE determined that a TD change of only 2 degrees would not be enough to drastically change the humidity, but would be significant enough to result in energy savings.

As with the condenser coil, DOE used the heat transfer equation to calculate the size of the improved coil from the baseline coil, assuming all other characteristics stayed the same. DOE calculated the new area assuming that both the length and the width of the coil would change at the same rate. DOE then used the cost model to calculate the added cost of materials to produce the larger coil. Because compressor capacity and power consumption are directly related to SET, reductions in the energy consumption are realized through an improved normalized energy consumption. Details of the TD are shown in Table 5.4.44.

Table 5.4.44 Details for "Evaporator Coil" Design Option

Code	Description	TD Reduction (°F)
EV1	Baseline	0
EV2	Improved	2

As with condenser coils, for improved evaporator coils, DOE assessed the incremental increase in cost due to additional material cost and separately evaluated the impact on shipping cost for each equipment class and size. The results are shown in Table 5.4.45.

Table 5.4.45 Details for "Evaporator Coil" Design Option, Continued

Equipment Class	Extra Material/Labor Cost ($)	Extra Shipping Cost ($)
DC.M.I – Small	$38.81	$4.03
DC.M.I – Large	$51.02	$5.63
DC.M.O – Small	$27.00	$2.80
DC.M.O – Large	$36.53	$4.03
RC.M – Small	$13.56	$1.45
RC.M – Large	$26.96	$3.68
DC.L.I – Small	$27.75	$2.25
DC.L.I – Large	$27.80	$3.03
DC.L.O – Small	$16.63	$1.65
DC.L.O – Large	$20.94	$2.28
RC.L – Small	$11.34	$1.30
RC.L – Large	$23.11	$3.31

5.4.5.6 Evaporator Fan Control

Evaporator fan controls save energy by allowing the evaporator fans to run at variable speed, or cycle on and off, during periods when the compressor is off. Without fan controls, the evaporator fans run at a constant speed at all times unless turned off manually. The proposed test procedure incorporates an off-cycle evaporator fan test to determine evaporator fan energy consumption during a compressor-off period. The proposed test procedure measures the effect of any fan control, with the following constraint: “controls shall be adjusted so that the greater of a 25% duty cycle or the manufacturer default is used for measuring off-cycle fan energy. For variable-speed controls, the greater of 25% fan speed or the manufacturer’s default fan speed shall be used for measuring off-cycle fan energy. When a cyclic control is used, at least three full ‘stir cycles’ are measured.” Because of these restrictions, the maximum energy savings that can be achieved is a 75% reduction in fan energy. DOE therefore set this as the energy savings achieved for the fan control technology option. These savings are realized as a reduction in the off-cycle fan energy consumption, which reduces both the direct energy consumption of the system and the heat contribution that must be removed.

Table 5.4.46 Details for “Evaporator Fan Control” Design Option

Code	Description	Off-Cycle Fan Power Multiplier	Cost Premium
EM1	Baseline	1	$-
EM2	Controlled	0.25	$300.00

5.4.5.7 Floating Head Pressure

The two technology levels for this design option are fixed head pressure and floating head pressure. Fixed head pressure involves keeping the compressor discharge pressure at a constantly fixed setting in order to enable operation over a variety of ambient temperatures in outdoor units. Generally, this is fixed at a high value in order to ensure that a sufficient amount of refrigerant can flow through the system, which also protects the condenser against freezing and maintains the necessary pressure difference across the expansion valve. However, this also keeps the condensing temperature fixed at a high level regardless of the ambient temperature.

Floating head pressure utilizes a control system and sophisticated expansion valves, typically electronic expansion valves (EEVs), to control the flow of refrigerant and keep liquid refrigerant from reaching the compressor. A pressure transducer may also be wired to the controller for pressure and temperature sensing. With floating head pressure, the compressor pressure and the saturated condensing temperature (SCT) float down to a minimum at which the compressor can operate. This typically corresponds to an SCT of 70 degrees. Compressor capacity and power consumption are directly related to SCT; compressors run more efficiently at a lower SCT. Thus, reductions in the energy consumption due to floating head pressure are realized through improved normalized energy consumption.

Table 5.4.47 Details for “Floating Head Pressure” Design Option

Code	Description	Cost Premium
-	Fixed Head Pressure	$-
FHP	Floating Head Pressure	$200.00

5.4.5.8 Defrost Controls

Defrost cycle control can reduce energy consumption by reducing the frequency and duration of defrost periods. Most walk-in defrost systems without controls are scheduled for certain times and last for a preset duration (time-time). Various control strategies include scheduling defrosts at certain times and using temperature termination control (time-temperature), only starting a defrost when necessary and then running for a set duration (temperature-time), and starting only when necessary and using temperature termination control (temperature-temperature). Still other strategies involve using an adaptive learning algorithm to predict when a defrost will be needed. Methods of detecting when a defrost is necessary and when a defrost cycle should terminate include optical sensing of frost on the evaporator coil or measurement of refrigerant temperature and pressure at various points on the refrigeration equipment.

Due to the complexity of the various control schemes, DOE did not attempt to analyze every one. However, in consultation with industry experts, DOE determined that without controls, most defrost cycles are scheduled to run more frequently and longer than necessary. Therefore, for the defrost control option, DOE assumed that a control strategy would result in half the amount of defrost power required, implemented in the energy model as a reduction by half in the number of defrost cycles per day. These savings are realized both as a reduction in the direct energy consumption of the system and a reduction in the amount of heat that must be removed by the system.

Table 5.4.48 Details for "Defrost Controls" Design Option

Code	Description	Cycle Divider	Cost Premium
DF1	Baseline	1	$-
DF2	Controlled	2	$185.00

5.4.6 Baseline Specifications

DOE defined baseline specifications for each equipment class. These specifications include dimensions, numbers of components, temperatures, nominal power ratings, and other case features that are necessary to calculate the energy consumption of each equipment class. In conjunction with the lowest technological level of each design option, the baseline specifications define the energy consumption and cost of the typical lowest efficiency equipment on the market. DOE established baseline specifications for each of the equipment classes modeled in the engineering analysis by reviewing available manufacturer data, selecting several representative units from available manufacturer data, and then aggregating the physical characteristics of the selected units. This process created a representative unit for each equipment class with average characteristics for physical parameters (e.g., volume, wall area), and typical performance for energy-consuming components. Table 5.4.49 through Table 5.4.52 show the specifications and units that are defined for envelopes and refrigeration systems, respectively.

Table 5.4.49 Baseline Specifications for Envelopes, Coolers

Equipment Class and Size	ND.C - Small	ND.C - Medium	ND.C - Large	D.C - Small	D.C - Medium	D.C - Large	Units
Internal Dry Bulb Temperature	35.0	35.0	35.0	35.0	35.0	35.0	F
External Dry Bulb Temperature	75.0	75.0	75.0	75.0	75.0	75.0	F
Internal RH	0.6	0.6	0.6	0.6	0.6	0.6	%
External RH	0.4	0.4	0.4	0.4	0.4	0.4	%
Height	7.6	9.5	12.0	6.6	7.6	7.6	ft
Length	10.0	12.0	25.0	6.0	10.2	80.0	ft
Width	8.0	20.0	30.0	6.0	7.0	15.0	ft
Passage Door Window Glass Area	0.9	0.9	0.9	0.0	0.0	0.0	ft^2
Display Door Width	2.5	2.5	2.5	2.5	2.5	2.5	ft
Display Door Height	6.3	6.3	6.3	6.3	6.3	6.3	ft
Passage Door Width	3.0	3.0	3.0	3.0	3.0	3.0	ft
Passage Door Height	7.0	7.0	7.0	7.0	7.0	7.0	ft
Freight Door Width	7.0	7.0	7.0	7.0	7.0	7.0	ft
Freight Door Height	9.0	9.0	12.0	9.0	9.0	12.0	ft
Number of Display Doors	0.0	0.0	0.0	3.0	8.0	50.0	#
Number of Passage Doors	1.0	1.0	2.0	1.0	1.0	2.0	#
Number of Freight Doors	0.0	1.0	1.0	0.0	0.0	0.0	#
Total External Surface Area	433.0	1088.0	2820.0	230.0	404.2	3844.0	ft^2
Floor Area	80.0	240.0	750.0	36.0	71.4	1200.0	ft^2
Total Passage Door Window Glass Area	0.9	0.9	1.8	0.0	0.0	0.0	ft^2
Non-Display Door Area	21.0	84.0	126.0	21.0	21.0	42.0	ft^2
Total Display Door Area	0.0	0.0	0.0	47.3	126.0	787.5	ft^2
Total Passage Door Area	21.0	21.0	42.0	21.0	21.0	42.0	ft^2
Total Freight Door Area	0.0	63.0	84.0	0.0	0.0	0.0	ft^2
Walls, Ceiling & Non-Display Door Area	332.0	764.0	1944.0	125.8	185.8	1814.5	ft^2
Case Gross Refrigerated Volume	606.7	2280.0	9000.0	237.0	542.6	9120.0	ft^3
Number of Light Tubes/Bulbs	1	1	3	4	10	52	#
Number of Circulation Fans	0	0	0	0	0	0	#
Walls/Floor Baseline Cost	$ 2,139	$ 4,005	$ 9,921	$ 1,069	$ 1,504	$ 8,900	$
Total Display Door Baseline Cost	$ -	$ -	$ -	$ 3,038	$ 8,100	$50,625	$
Total Baseline Cost	$ 2,139	$ 4,005	$ 9,921	$ 4,106	$ 9,604	$59,525	$

Table 5.4.50 Baseline Specifications for Envelopes, Freezers

Equipment Class and Size	ND.F - Small	ND.F - Medium	ND.F - Large	D.F - Small	D.F - Medium	D.F - Large	Units
Internal Dry Bulb Temperature	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	F
External Dry Bulb Temperature	75.0	75.0	75.0	75.0	75.0	75.0	F
Internal RH	0.6	0.6	0.6	0.6	0.6	0.6	%
External RH	0.4	0.4	0.4	0.4	0.4	0.4	%
EER	6.3	6.3	6.3	6.3	6.3	6.3	Btu/W-h
Height	7.6	9.5	12.0	6.6	7.6	7.6	ft
Length	8.0	9.0	25.0	6.0	10.2	80.0	ft
Width	6.0	20.0	20.0	6.0	7.0	15.0	ft
Passage Door Window Glass Area	0.9	0.9	0.9	0.0	0.0	0.0	ft^2
Display Door Width	2.5	2.5	2.5	2.5	2.5	2.5	ft
Display Door Height	6.3	6.3	6.3	6.3	6.3	6.3	ft
Passage Door Width	3.0	3.0	3.0	3.0	3.0	3.0	ft
Passage Door Height	7.0	7.0	7.0	7.0	7.0	7.0	ft
Freight Door Width	7.0	7.0	7.0	7.0	7.0	7.0	ft
Freight Door Height	9.0	9.0	12.0	9.0	9.0	12.0	ft
Number of Display Doors	0.0	0.0	0.0	3.0	8.0	50.0	#
Number of Passage Doors	1.0	1.0	2.0	1.0	1.0	2.0	#
Number of Freight Doors	0.0	1.0	1.0	0.0	0.0	0.0	#
Total External Surface Area	308.8	911.0	2080.0	230.0	404.2	3844.0	ft^2
Floor Area	48.0	180.0	500.0	36.0	71.4	1200.0	ft^2
Total Passage Door Window Glass Area	0.9	0.9	1.8	0.0	0.0	0.0	ft^2
Non-Display Door Area	21.0	84.0	126.0	21.0	21.0	42.0	ft^2
Total Display Door Area	0.0	0.0	0.0	47.3	126.0	787.5	ft^2
Total Passage Door Area	21.0	21.0	42.0	21.0	21.0	42.0	ft^2
Total Freight Door Area	0.0	63.0	84.0	0.0	0.0	0.0	ft^2
Walls, Ceiling & Non-Display Door Area	239.8	647.0	1454.0	125.8	185.8	1814.5	ft^2
Case Gross Refrigerated Volume	364.8	1710.0	6000.0	237.0	542.6	9120.0	ft^3
Number of Light Tubes/Bulbs	1	1	3	4	9	52	#
Number of Circulation Fans	0	0	0	0	0	0	#
Walls/Floor Baseline Cost	$ 2,111	$ 5,053	$11,118	$ 1,373	$ 1,982	$16,394	$
Total Display Door Baseline Cost	$ -	$ -	$ -	$ 3,375	$ 9,000	$56,250	$
Total Baseline Cost	$ 2,111	$ 5,053	$11,118	$ 4,748	$10,982	$72,644	$

Table 5.4.51 Baseline Specifications for Refrigeration Systems, Medium Temperature

Equipment Class and Size	**DC.M.I – Small**	**DC.M.I – Large**	**DC.M.O – Small**	**DC.M.O – Large**	**MC.M – Small**	**MC.M – Large**
Interior Temperature [F]	35	35	35	35	35	35
Saturated Evaporator Temperature (SET) Nominal [F]	25	25	25	25	25	25
Saturated Condenser Temperature (SCT) Nominal [F]	115	115	115	115	-	-
Design Ambient Temperature [F]	90	90	95	95	-	-
Nominal Evaporator Coil Capacity [Btu/h]	15,600	26,000	15,600	26,000	9,700	31,200
Evaporator Coil Height [in]	12.5	12.5	12.5	12.5	13.5	12.5
Evaporator Coil Width [in]	48.0	80.0	48.0	80.0	31.3	96.0
Evaporator Coil Depth [in]	4	4	4	4	4	4
Evaporator Fan Type	ECM	ECM	ECM	ECM	ECM	ECM
Evaporator Fan Horsepower [HP]	1/15	1/15	1/15	1/15	1/15	1/15
Number of Evaporator Fans [#]	3	5	3	5	2	6
Condenser Coil Height [in]	15.0	18.0	18.0	18.0	-	-
Condenser Coil Width [in]	16.0	30.0	30.0	30.0	-	-
Condenser Coil Depth [in]	3	3	3	3	-	-
Condenser Fan Type	PSC	PSC	PSC	PSC	-	-
Condenser Fan Horsepower [HP]	1/6	1/6	1/6	1/6	-	-
Number of Condenser Fans [#]	1	2	2	2	-	-
Nominal Compressor Capacity [Btu/h]	15,000	26,000	15,000	24,000	-	-
Defrost Mechanism Type	-	-	-	-	-	-
Defrost Time per Day [hrs]	-	-	-	-	-	-
Defrost+Drain Heater Power [W]	-	-	-	-	-	-

Table 5.4.52 Baseline Specifications for Refrigeration Systems, Low Temperature

Equipment Class and Size	DC.L.I – Small	DC.L.I – Large	DC.L.O – Small	DC.L.O – Large	MC.L – Small	MC.L – Large
Interior Temperature [F]	-10	-10	-10	-10	-10	-10
Saturated Evaporator Temperature (SET) Nominal [F]	-20	-20	-20	-20	-20	-20
Saturated Condenser Temperature (SCT) Nominal [F]	110	110	110	110	-	-
Design Ambient Temperature [F]	90	90	95	95	-	-
Nominal Evaporator Coil Capacity [Btu/h]	6,000	12,000	6,000	12,000	6,000	24,000
Evaporator Coil Height [in]	13.5	12.5	13.5	12.5	13.5	12.5
Evaporator Coil Width [in]	31.9	48.0	31.9	48.0	31.9	96.0
Evaporator Coil Depth [in]	4	4	4	4	4	4.25
Evaporator Fan Type	ECM	ECM	ECM	ECM	ECM	ECM
Evaporator Fan Horsepower [HP]	1/15	1/15	1/15	1/15	1/15	1/15
Number of Evaporator Fans [#]	2	3	2	3	2	6
Condenser Coil Height [in]	15.0	18.0	18.0	18.0	-	-
Condenser Coil Width [in]	16.0	30.0	30.0	30.0	-	-
Condenser Coil Depth [in]	3	3	3	3	-	-
Condenser Fan Type	PSC	PSC	PSC	PSC	-	-
Condenser Fan Horsepower [HP]	1/6	1/6	1/6	1/6	-	-
Number of Condenser Fans [#]	1	2	1	2	-	-
Nominal Compressor Capacity [Btu/h]	6,500	12,500	6,000	11,500	-	-
Defrost Mechanism Type	ELE	ELE	ELE	ELE	-	-
Defrost Time per Day [hrs]	1	1	1	1	1	1
Defrost+Drain Heater Power [W]	1,656	2,756	1,656	2,756	1,656	5,456

5.4.7 Non-Numerical Assumptions

In developing the energy consumption model, DOE made certain non-numerical assumptions concerning the analysis. These include general assumptions about the analysis as well as specific assumptions regarding load components and design options.

5.4.7.1 Assumptions Concerning the Envelope Energy Calculations

The temperature and humidity inside the cooled space of the WICF and of the surrounding environment was considered to be constant. While a real walk-in envelope sited in the outdoors may consume more or less energy relative to a walk-in sited indoors, this was ignored in the engineering analysis for two reasons. First, the WICF test procedure does not account for weather effects. It compares the performance of all walk-ins, designed for both the indoors and outdoors, in the same manner. Secondly, accounting for large regional variation in weather would result in a variable standard that undermines the "level playing field" that DOE is attempting to protect.

The cooled space of the walk-in was modeled as an empty space. No accounting for food (or other) product variation, such as type of product, rate of product turnover or product initial temperature was considered. Therefore the heat capacity (or thermal mass) nor the volume of stored products was considered which would have otherwise impacted air movement, total cooled air volume and transient temperatures of the cooled space. This was to eliminate confounding factors so that design options could be compared within the engineering analysis. (However, product loading was considered in the Energy Use Analysis (chapter 7 of the preliminary TSD) to better replicate real-world conditions.)

If air curtains were selected as a design option in the analysis, it was assumed that the device would only operate for as long as a door that it was protecting was opened. Therefore, the door opening time exactly equals the air curtain fan motor operation time. This was used to calculate the associated electrical energy consumed to reduce air exchange. The majority of commercially available air curtains, considered by the DOE, include electronic switches that sense door openings as a standard option.

All of the components were modeled as newly manufactured. Wear on gaskets, joints etc were not considered. Foam R-value degradation caused by water infiltration was not considered. However, DOE used long term thermal resistance (LTTR) values of both XPS and PU foam for all of the heat conduction calculations. This reflects the use of an LTTR measurement in DOE's proposed test procedure for WICF.

In previous related rulings, vacuum insulated panels have not been considered viable design options. However, due to recent increase in production, corresponding drop in cost and efforts by VIP manufacturers to break into the walk-in market by making a product that is better suited for panel construction, DOE considered VIPs as a design option. While they are still far more expensive than other options, DOE recognizes that they are technically viable and commercial available for use in WICF.

The walk-ins were modeled as simple cuboids. No unique geometries were considered such as L-shaped systems or other designs that have irregular external surface area to volume ratios. Due to the variation in design, various geometries would have made the analysis too complex. In addition, co-sited walk-ins or walk-ins that share a wall with another walk-in were not considered, again due to the vast variation in design. DOE considers the impact of this approach to be limited because the key parameter considered in the analysis was the total external surface area which is most strongly correlated with WICF energy consumption.

Radiation heat transfer was not directly considered in the energy modeling of WICF. Since outdoor conditions were not considered and it was assumed that WICF are not normally sited near high temperature radiative heat sources such as boilers or other high heat equipment, this is a reasonable assumption. However, radiation is indirectly considered in the U-value calculations used to measure the performance of glass display doors. The Window 5.2 software models this form of heat transfer which is largely reduced by low emissivity coatings.

While in practice, the frequency of door opening events would vary depending on the time of day and walk-in type, DOE considered the door openings to occur at regular intervals throughout a twenty-four hour period. This simplifying assumption ignores the transient effects of air infiltration on internal temperature of the walk-in among other transient phenomena. Because all walk-ins within a product class were compared using the same assumptions, this was considered a reasonable simplification. In addition, the overall impact on daily or annual energy consumption is believed to be limited and these assumptions reflect the values of the proposed WICF test procedure. 75 FR 197

5.4.7.2 Assumptions Concerning the Refrigeration Energy Consumption

DOE assumed that all conditions are based on new equipment tested in a controlled-environment chamber subjected to AHRI 1250-2009, the proposed refrigeration test procedure. Once the test procedure is finalized, manufacturers that certify their equipment to comply with Federal standards will be required to test new units to this test method, which specifies certain ambient temperature, humidity, and other requirements.

DOE did not consider hot-gas defrost as a design option for defrost mechanisms in multiplex condensing systems (see chapter 4, screening analysis). During hot-gas defrost, hot refrigerant from the compressor rack bypasses the condenser and expansion device and is piped directly to the evaporator coil, melting the frost on the coil. The test procedure does not capture the heat added to a walk-in during a hot-gas defrost cycle. Therefore, DOE did not consider this technique.

Due to the ongoing phaseout of HCFC refrigerants in the WICF industry, HFC refrigerants are most likely to be used in this equipment in the future. Other alternative refrigerants, such as ammonia, hydrocarbons, and CO_2, were not considered in this analysis, as they are not currently used in domestically manufactured WICF refrigeration systems. Additionally, some of these refrigerants, including ammonia, could be limited by State and local building codes due to toxicity concerns. Common HFC refrigerants used in refrigeration equipment include R-507 and R-404A. DOE assumed that only HFC refrigerants will be utilized by WICF refrigeration systems and has based its analysis solely upon equipment containing those refrigerants.

DOE assumed that there are no cyclic losses associated with the refrigeration system operation. In steady state operation, the majority of the refrigerant charge is located in the high pressure side of the system. During an off-cycle, the refrigerant migrates to the evaporator, because the evaporator is at a lower pressure than the condenser. At the start of the next operating cycle, the excess refrigerant charge in the low side of the system must be transferred to the high side of the system to achieve steady state operation. Liquid refrigerant in the evaporator flows to the accumulator, the suction pressure drops to a value low enough to vaporize the liquid, and the compressor pumps the vapor to the condenser. This process can take several minutes, during which time the refrigeration system does not operate at steady state capacity. The cyclic losses are greater in systems having larger coil sizes as a result of the greater amount of refrigerant charge in such systems. Any However, because the proposed test procedure only measures the compressor energy consumption when the compressor is running at steady state, these losses are not accounted for.

In the baseline, the head pressure of the system is fixed at a high value regardless of the external temperature, in order to ensure that a sufficient amount of refrigerant can flow through the system, which also protects the condenser against freezing and maintains the necessary pressure difference across the expansion valve. One of the design options is implementing floating head pressure, in which the refrigerant flow is dynamically controlled over a broad range of external temperatures. In this case, condensing temperatures lower than the temperatures of 90 or 95 degrees necessary for a fixed-head pressure system can be utilized. However, DOE assumed that the limit to which the condensing temperature could float is 70 degrees. Compressor performance maps do not typically show data at condensing temperatures beyond 70 degrees, and compressor performance is not guaranteed at lower temperatures. Furthermore, DOE assumed that for systems with floating head pressure, as the condensing temperature decreased with the ambient temperature, the temperature difference (TD) between the condensing and ambient temperature would stay the same.

5.4.8 Numerical Constants and Assumptions

Table 5.4.53 Envelope Assumptions

Parameter	Value	Units	Source
External Dry Bulb Temperature	75	F	Assumed
Cooler- Internal Dry Bulb Temperature	35	F	Standard medium-temperature set-point, WICF Manufacturers
Concrete Floor temperature, Cooler	60	F	DOE WICF Proposed Test Procedure NOPR
Concrete Floor temperature, Freezer	65	F	DOE WICF Proposed Test Procedure NOPR
Freezer- Internal Dry Bulb Temperature	-10	F	Standard low-temperature set-point, WICF Manufacturers
Internal RH	60%	%	Assumed
External RH	40%	%	Population weighted national average humidity, DOE analysis
Cooler-EER	12.4	Btu/W-h	Energy Efficiency Ratio based on AHRI Refrigeration Equipment Test Procedure
Freezer-EER	6.3	Btu/W-h	Energy Efficiency Ratio based on AHRI Refrigeration Equipment Test Procedure
Daily Time Period	24	h	Assumed
Acceleration of Gravity	32.2	ft/s^2	Assumed
LTTR-XPS	5.61	ft^2-F-h/Btu	As tested by a third party laboratory
LTTR-Polyurethane (Foam-in-place@ 2.4 lb/ft^3 density)	6.20	ft^2-F-h/Btu	As tested by a third party laboratory
External Equivalent Convective Film Coefficient	0.68	ft^2-F-h/Btu	Assumed
Internal Equivalent Convective Film Coefficient	0.25	ft^2-F-h/Btu	Assumed
Floor Equivalent Convective Film Coefficient	0.87	ft^2-F-h/Btu	Based on Finite Element Heat Transfer Model, DOE Analysis
Rated power, 2-way pressure air freezer relief valve heater	23	W	Component Manufacturer Data
2-way pressure air relief valve heater, Operation per day	24	h	Component Manufacturer Data
Average Shipping Distance to Distribution Center	1000	miles	DOE Estimate
Door Flow Factor	0.8	-	ASHRAE Fundamentals
Display Door Width	2.5	ft	Assumed
Display Door Height	6.3	ft	Assumed
Passage Door Width	3	ft	Assumed
Passage Door Height	7	ft	Assumed
Freight Door Width	7	ft	Assumed
Freight Door Height	9	ft	Assumed
Large Freight Door Width	7	ft	Assumed
Large Freight Door Height	12	ft	Assumed
Infiltration Parameters			
Display Doors			
Door Openings Per Day, P	72	#	DOE WICF Proposed Test Procedure NOPR
Door Open/Close Time	8	seconds	DOE WICF Proposed Test Procedure NOPR
Time Door Stands Open	0	min/day	DOE WICF Proposed Test Procedure NOPR
Passage Doors			
Door Openings Per Day, P	60	#	DOE WICF Proposed Test Procedure NOPR
Door Open/Close Time	12	seconds	DOE WICF Proposed Test Procedure NOPR
Time Door Stands Open	15	min/day	DOE WICF Proposed Test Procedure NOPR

Freight Doors			
Door Openings Per Day, P	60	#	DOE WICF Proposed Test Procedure NOPR
Door Open/Close Time	12	seconds	DOE WICF Proposed Test Procedure NOPR
Time Door Stands Open	15	min/day	DOE WICF Proposed Test Procedure NOPR
Anti-sweat power, with display door option DR2	1.0	W/ft	DOE Estimate
Anti-sweat power, with display door option DR3 or higher	0.0	W/ft	DOE Estimate
Percentage of anti-sweat heat transferred into the walk-in	70	%	DOE Estimate
Freezer Passage Door Heat Wire Operation Time Per Day	24	h	Assumed
Control System Average Power	5	W	Assumed
Manufacturer Selling Price Mark-up	1.39	-	Assumed

Table 5.4.54 Refrigeration System Assumptions Associated with Defrost

Constants Specified by the Test Procedure	Value	Units	Source
Infiltration coefficient k13	0.0001	cfm-hr/Btu	Proposed Test Procedure
Infiltration coefficient k14	3.49	cfm	Proposed Test Procedure
Humidity ratio of incoming air	0.0105	lb water/lb air	Proposed Test Procedure
Density of incoming air	0.073	lb/ft^3	Proposed Test Procedure
Physical Properties of Materials			
Specific heat of ice	0.487	Btu/lb-R	ASHRAE Handbook of Fundamentals, 2009
Specific heat of water	1.00	Btu/lb-R	ASHRAE Handbook of Fundamentals
Latent heat of fusion of water	143.5	Btu/lb	ASHRAE Handbook of Fundamentals
Meltwater temperature	32	F	ASHRAE Handbook of Fundamentals, 2009
Other Assumptions			
Length of defrost	15	min	DOE Assumption
Amount of time between defrosts	6	h	DOE Assumption

Table 5.4.55 Refrigeration System Baseline TD Assumptions

Class	Ambient (°F)	Baseline SCT (°F)	Baseline TD (°F)
DC.M.I	90	115	25
DC.L.I	90	110	20
DC.M.O	95	115	20
DC.L.O	95	110	10

5.4.9 Model Components: Envelope

Figure 5.4.5 shows the components of the energy consumption model used in the engineering analysis. The model calculates energy consumption in two major subsections, heat load and electrical energy consumption, which are further broken out by the underlying components or physics.

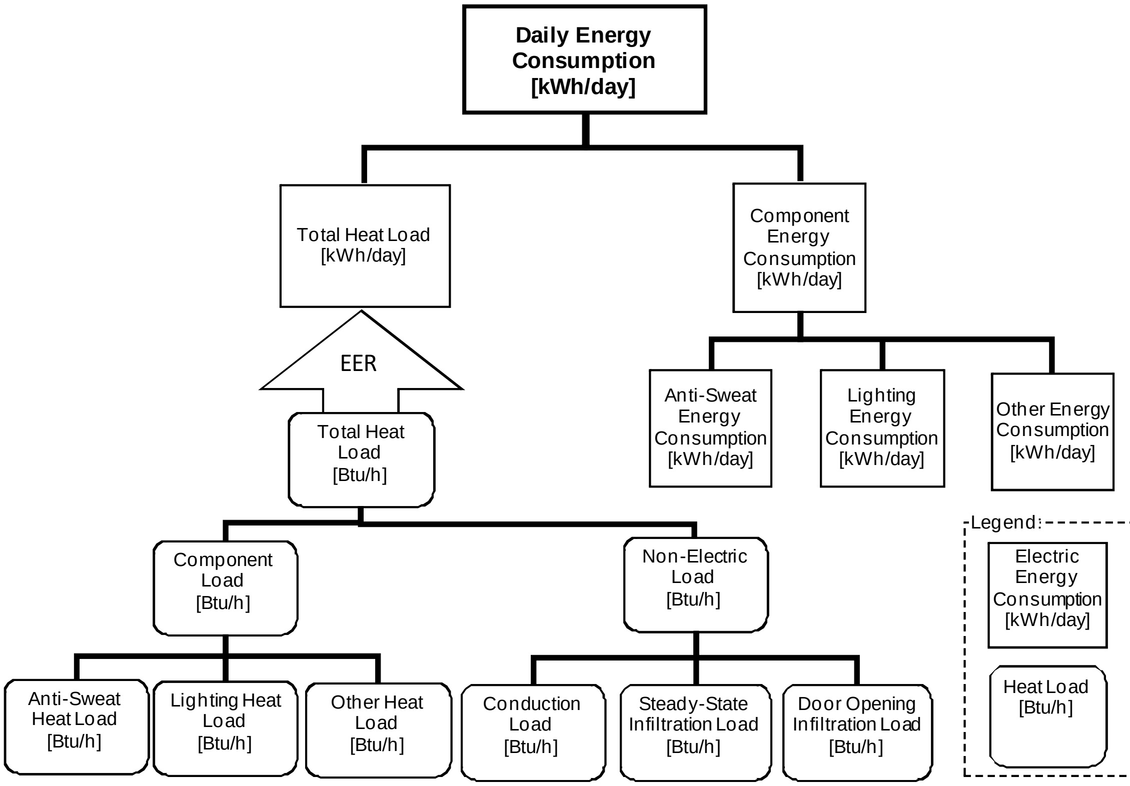

Figure 5.4.5 Overview of Envelope Engineering Analysis Calculations

5.4.9.1 Heat Conduction Load

The heat transfer via conduction in the engineering analysis is broken into non-glass and glass related conduction. Non-glass includes the typical insulated walls, ceiling, floors and non-transparent doors. The glass calculations cover display door glass and glass inset windows. The heat transfer, in Btu/h, is calculated for each of these components based on the temperature differential between the cooled space and the surroundings, the thermal resistance of the material i.e. R-value of foam or the U-value of glass, and the associated surface area of that component or components. These properties change based on the current design option level. For example, four inch foam panel versus six inch foam panel.

After completing these calculations, the total load is summed and then converted into units of kWh/day utilizing the assumed Energy Efficiency Ratio (EER). The EER value corresponds to the current walk-in type being analyzed (freezer or cooler). Further clarification of the use of an EER is described below.

5.4.9.2 Energy Efficiency Ratio (EER)

In order to estimate the associated refrigeration equipment energy consumption due to the envelope energy losses, DOE implemented the use of refrigeration equipment EER. The EER represents the energy performance of the refrigeration equipment as a ratio of units of thermal energy removed from the conditioned walk-in space to units of electrical energy input (to operate refrigeration compressors, fans etc). Therefore, this ratio represents the efficiency of the refrigeration equipment. DOE assumed two different EER values that correspond to medium and low temperature refrigeration systems of 12.4 Btu/W-h and 6.3 Btu/W-h[xii], respectively. Depending on the temperature being analyzed, the envelope engineering analysis model selects the appropriate EER to convert the thermal energy into units of electrical energy used.

This "conversion" helps the load due to the envelope be more easily understood. With units of thermal energy in kWh, the thermal load could be directly summed with the kWh due to use of lights, anti-sweat heaters and other electrical components. The result is the total energy consumption per day in kWh.

5.4.9.3 Infiltration Load: Steady-State

The amount of embodied energy in an air sample is primarily a function of its temperature (and therefore density). This property is typically referred to as the enthalpy in any thermodynamic system (such as a walk-in cooler or freezer). The required amount of energy needed to remove heat from the air is calculated as the difference between the enthalpy of air entering the refrigerated space and enthalpy of the air inside the refrigerated space. This calculation is commonly used when designing walk-ins and typically uses dry-bulb and wet-bulb temperatures. In the engineering analysis the difference between the infiltrating and exfiltrating air, per unit cubic foot, is calculated using the functional relationship between temperature and enthalpy.

Then using the estimated infiltration rate per unit surface area of the walk-in the thermal energy consumption, in units of Btu/h, is directly calculated. As with the conduction load, this thermal energy is converted into units of kWh/day using the appropriate EER value.

5.4.9.4 Infiltration Load: Door Opening

The heat load due to door openings is calculated in an identical manner as the steady-state infiltration calculations using the enthalpy difference of the exchanged air. In order to calculate the volume of air exchanged per door opening, DOE used equations developed by ASHRAE[xiii]. With known air properties, door geometry and assumptions about door opening frequency, duration, the number of doors and the effectiveness of infiltration reduction devices, the volume of air exchanged for each unique door opening event is computed. The assumptions change with various design options. For example, the infiltration reduction effectiveness changes depending if a strip curtain or air curtain is in place or a display door is being opened versus a large freight door. As for other thermal energy calculations the total load in Btu/h is then converted into kWh/day using the EER.

5.4.9.5 Anti-Sweat and Other Heater Wire Electrical Load

Resistive heater wire is rated in units of W/ft. For a given door the perimeter length is calculated and multiplied by the wire rating to compute the total electrical load per door. The amount of time per day that the wire is powered is calculated using the assumed percent time off (PTO) if an anti-sweat controller is selected or not. In addition the rated power of the heater wire changes based on the design option level of the display door. With total wattage and operation time per day, the total kWh/day is then directly calculated.

5.4.9.6 Lighting Electrical Load

The lighting electrical load is calculated in an identical manner as the anti-sweat systems. Using the rated power of the light and assumptions about PTO based on the current control system design option, the kWh/day from lights is computed.

5.4.9.7 Other Electrical Devices

As with the previous devices, the device rated power such as the heated by-directional pressure relief valve used in walk-in freezers or the power use of the control system hardware is multiplied by the hours of use per day to get the total kWh/day consumption.

5.4.9.8 Additional Heat Load Due to Electrical Device Waste Heat

Using the total energy consumption of all electrical devices sited inside the walk-in (air curtain power, for example, is not included because they are mounted external to the refrigerated space of the walk-in) an associated additional heat load is calculated. This thermal load is converted using the EER into an effective extra compressor load due to the operation of these electrical devices.

The energy consumption attributed to all components is totaled to compute the full product incremental energy consumptions for up to fifteen unique design option levels. The incremental cost of each design option is also totaled in order to plot the cost-efficiency curves for each product class and size analysis point (small, medium and large). The final cost-efficiency curve displays the design options ordered by relative cost-effectiveness.

5.4.10 Model Components: Refrigeration

The energy consumption model analytically calculates energy consumption using the same methodology as the proposed test procedure. In the proposed test procedure, the refrigeration system is tested under certain conditions to determine steady state capacity and power. Then an assumed non-refrigeration load attributed to the envelope is calculated. This methodology assumes that the refrigeration system is sized to the expected load, allowing refrigeration systems to be compared with each other even when the tester does not know the characteristics of the envelope with which the refrigeration system will ultimately be paired. From the steady state power, the capacity, and the expected load profile, the annual energy consumption can be calculated.

DOE’s ultimate metric that it chose for expressing the performance of the refrigeration system is normalized energy consumption; that is, the total annual energy consumption divided by the net capacity of the system. DOE chose to measure normalized energy consumption instead of total energy consumption because the annual energy consumption depends partly on the capacity of the system, which is used to determine the load factors or duty cycles. Some design options increase the capacity, which would tend to reduce the energy consumption by allowing lower duty cycles. However, under the proposed test procedure, a system with a higher capacity would be assumed to have a larger non-refrigeration envelope load, which could increase the duty cycle. To account for these competing effects, DOE normalized the energy consumption by capacity. This rewards the design options that increase the efficiency of the refrigeration system: not the ones that save more net energy, but the ones that save more energy for their size.

Error! Reference source not found. Figure 5.4.6 presents a schematic showing the components in the energy consumption model for dedicated condensing systems. For indoor systems, the test procedure assumes that the ambient temperature does not change, and therefore the energy consumption does not change from day to day. In this case, the energy consumption per day is multiplied by 365 to get annual energy consumption. For outdoor systems, a yearly temperature profile is assumed by the proposed test procedure, which lists the number of hours in each temperature "bin," a range of 5 degrees. In this case, the net capacity and system power are tested at 3 test temperatures, and then calculated for all the other temperature bins using linear interpolation. Then the annual energy consumption is calculated by summing the energy consumption for each temperature bin multiplied by the number of hours in the bin.

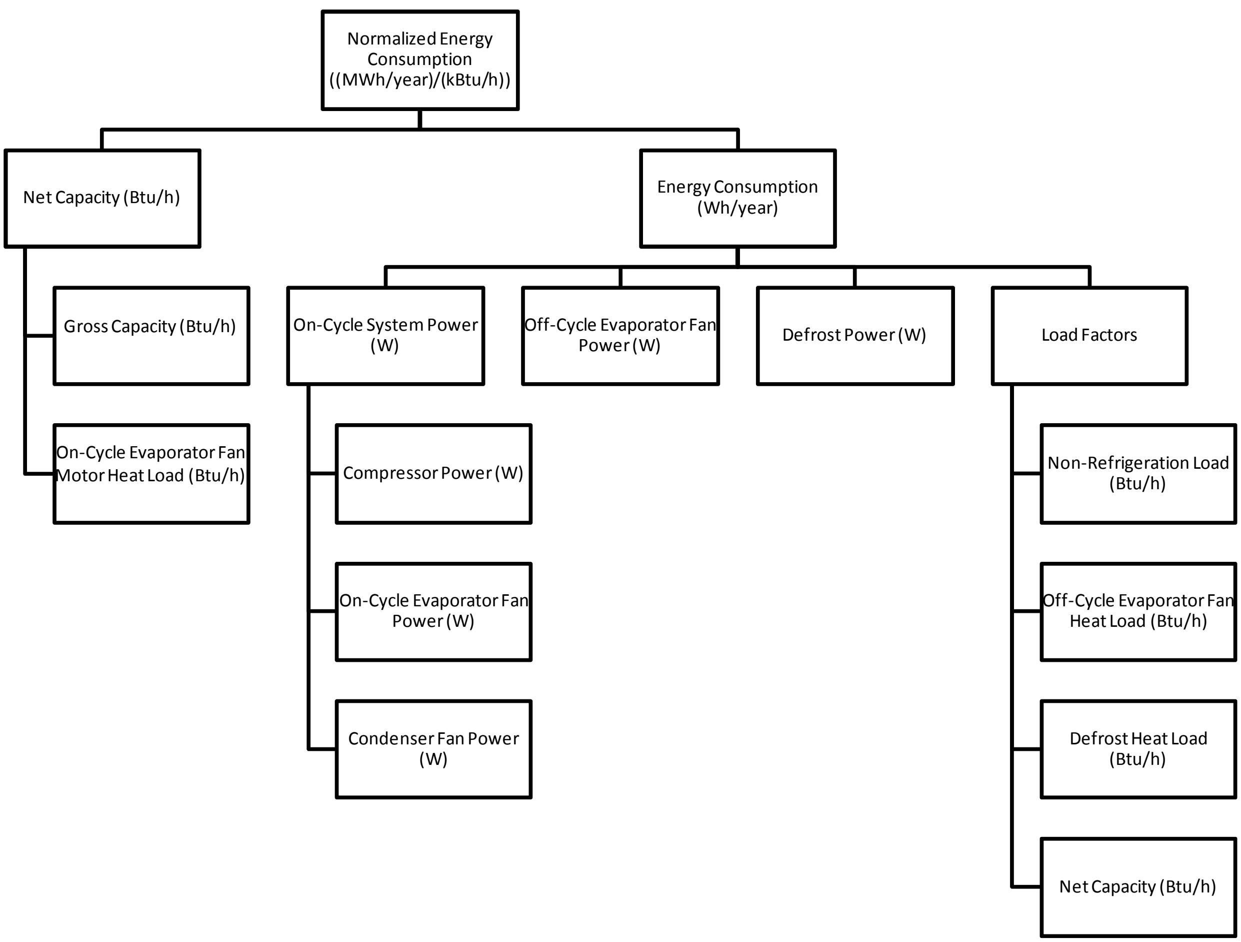

Figure 5.4.6 Energy Consumption Model for Dedicated Condensing Systems

5.4.10.1 Net Capacity

The net capacity is calculated as the gross capacity of the compressor, less the heat given off by the evaporator fans when the compressor is running. Defrost heat is not considered because it is measured with a separate test, and would not be accounted for in the test procedure during the test of net capacity. The gross compressor capacity is calculated by using the compressor model described in section 6.4 of ARI Standard 540-2004 (ARI 540), *Performance Rating of Positive Displacement Refrigerant Compressors and Compressor Units*. This model is based on a 10-coefficient polynomial derived from empirical compressor performance data for capacity, power, mass flow, current, and efficiency. The coefficients are derived for each of these parameters as a function of SET and SCT. Compressor coefficients, or tabulated empirical data (from which coefficients can be derived), are available from compressor manufacturers. The gross capacity is determined from the published coefficients, the SET, and the SCT.

5.4.10.2 On-Cycle System Power

The on-cycle system power is the sum of the compressor power, the on-cycle evaporator fan power, and the condenser fan power. Similar to the capacity, the compressor power is determined from the published compressor coefficients, the SET, and the SCT.

5.4.10.3 Load Factors

The load factors represent the fraction of the time that the compressor is running at both a "high load" period and a "low load" period. The high-load period corresponds to the time during the day when the walk-in experiences a high heat load due to product being stored in the walk-in, employees entering and leaving, etc. The low-load period corresponds to the time during the day when the walk-in is not being accessed, and experiences a low heat load: night, off-business hours, etc. Per the proposed test procedure, 1/3 of the time is experienced at a high load and 2/3 at a low load. The corresponding load factors, LFH (load factor at high load) and LFL (load factor at low load) are calculated from the heat load on the walk-in at a high and low period respectively (including non-refrigeration heat load, evaporator fan heat load, and defrost heat load), and the net capacity of the refrigeration system to reject this load. This determines how frequently the compressor must run at a high and low period.

$$LFH = \frac{WLH(t_j)}{q_{ss}(t_j)} \quad \text{(if } WLH(t_j) > q'_{ss}(t_j),\ LFH = 1\text{)} \qquad \textbf{Eq. 5.2}$$

$$LFL = \frac{WLL(t_j)}{q_{ss}(t_j)} \quad \text{(if } WLL(t_j) > q'_{ss}(t_j),\ LFL = 1\text{)} \qquad \textbf{Eq. 5.3}$$

where:

WLH is the heat load on the walk-in at a high period
WLL is the heat load on the walk-in at a low period
q_{ss} is the net capacity.

WLH and WLL include all heat loads on the walk-in: non-refrigeration heat load, evaporator fan heat load, and defrost heat load:

$$WLH(t_j) = BLH(t_j) + 3.412 * EF_{comp,off}(1 - LFH) + \dot{Q}_{DF} \quad \textbf{Eq.5.4}$$

$$WLL(t_j) = BLL(t_j) + 3.412 * EF_{comp,off}(1 - LFL) + \dot{Q}_{DF} \quad \textbf{Eq.5.5}$$

where:

BLH and BLL are the non-refrigeration heat load at a high and low period, respectively,

$EF_{comp,off}$ is the evaporator fan motor power in W (multiplied by 3.412 Btu/h/W to get heat load,

Q_{df} is the defrost heat load.

(The on-cycle evaporator fan motor heat is not included in this equation because it is already accounted for in the net capacity.)

The non-refrigeration heat loads are derived from the net capacity and, for outdoor units, an assumed temperature profile. As discussed above, this is because the methodology assumes that the refrigeration system is sized to the expected load, allowing refrigeration systems to be compared with each other even when the tester does not know the characteristics of the envelope that the refrigeration system will ultimately be paired with.

Figure 5.4.7 presents a schematic showing the components in the energy consumption model for unit coolers connected to multiplex condensing systems. The model is similar, except the power attributed to the unit cooler is calculated by assuming a certain efficiency, or EER, for the multiplex system. In this case, the EER is assumed to be constant throughout the year, so energy consumption per day is multiplied by 365 to get annual energy consumption.

The default EER values are contained in the proposed test procedure. The test procedure provides tables of EER values for both medium and low temperature systems. The EER values are expressed in Btu/Wh, as a function of adjusted dew point temperature. The test procedure provides that the adjusted dew point temperature for a medium temperature system shall be 19 ˚F and shall -26 ˚F for a low temperature system, unless the unit cooler is rated at a suction dew point other than 19 ˚F for a refrigerator or -26 ˚F for a freezer, in which case the adjusted dew point value shall be 2 ˚F less than the unit cooler rating suction dew point. (cite)

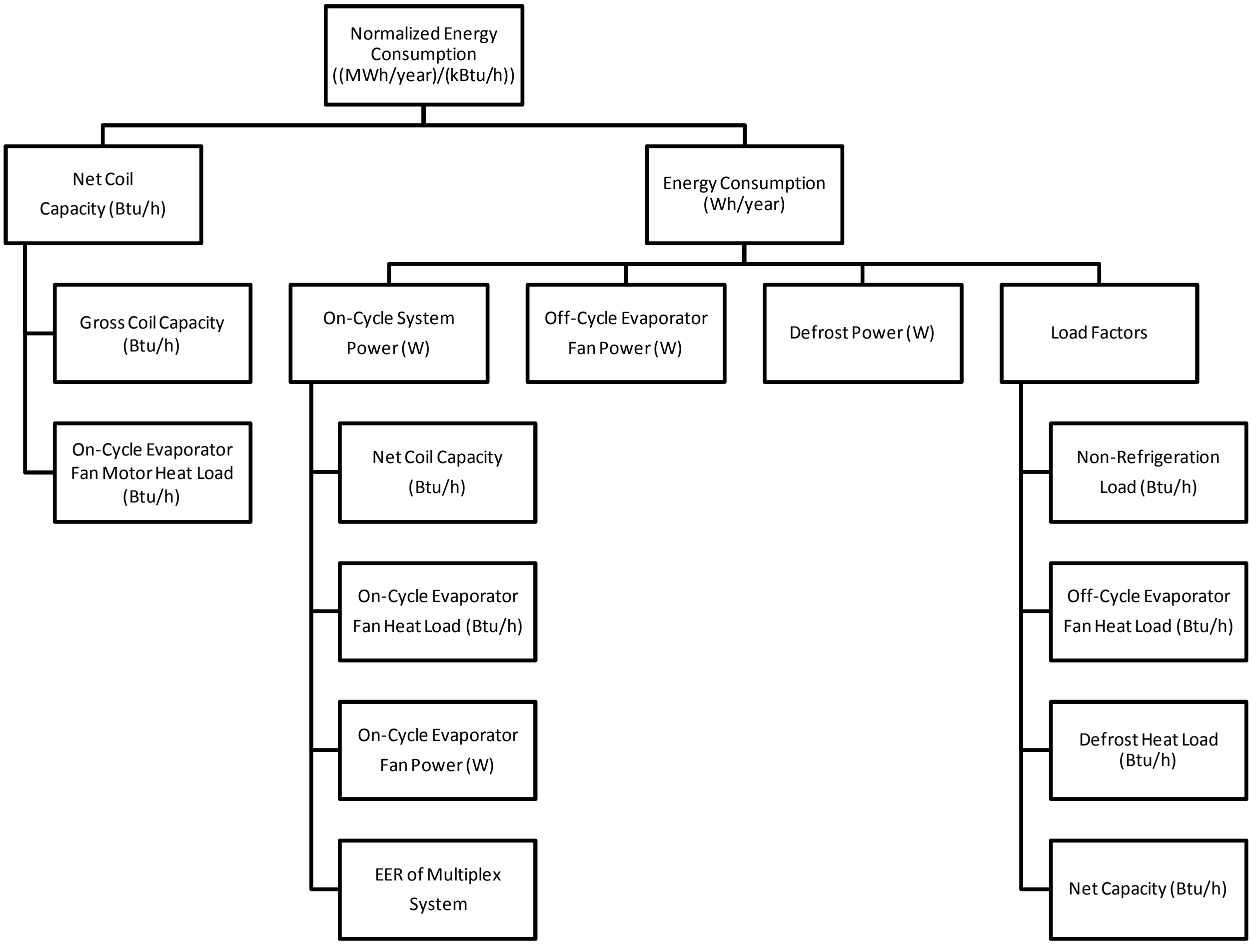

Figure 5.4.7 Energy Consumption Model for Unit Coolers Connected to Multiplex Condensing Systems

5.5 COST-EFFICIENCY CURVES

Below are the cost-efficiency curves for the envelope and refrigeration equipment, respectively.

As explained in section 5.4.10, DOE's ultimate metric that it chose for expressing the performance of the refrigeration system is normalized energy consumption; that is, the total annual energy consumption divided by the net capacity of the system. Likewise, DOE divided the price by the net capacity at each efficiency level. One notable observation for some equipment classes is that for a few efficiency levels above the baseline, the estimated cost per unit energy consumption appears to decrease. This indicates that for these efficiency levels, although the absolute price of the unit increases, the capacity also increases at a faster rate, so the price per capacity decreases.

5.5.1 Envelope Cost-Efficiency Curves

Table 5.5.1 Cost-Efficiency Data for the ND.C. Small Equipment Class

Efficiency Level	**Daily Energy Use** [kWh/day]	**MPC Mfg. Cost** [$]	**MSP Mfg. Price** [$]	**Design Option**
L0	5.18	$2,224	$3,358	Baseline
L1	2.99	$2,315	$3,484	L0 + SC
L2	2.74	$2,349	$3,531	L1 + LED
L3	1.91	$2,600	$3,940	L2 + FLR2
L4	1.81	$2,673	$4,054	L3 + TCK2
L5	1.80	$2,682	$4,067	L4 + XC
L6	1.68	$2,792	$4,237	L5 + TCK3
L7	1.64	$2,841	$4,309	L6 + FLR3
L8	1.49	$3,033	$4,607	L7 + TCK4
L9	1.39	$3,226	$4,904	L8 + TCK5
L10	1.15	$4,226	$6,294	L9 + VEST
L11	0.96	$6,224	$8,921	L10 + INSH1
L12	0.87	$7,345	$10,479	L11 + VIP
L13	0.83	$7,869	$11,206	L12 + ATG

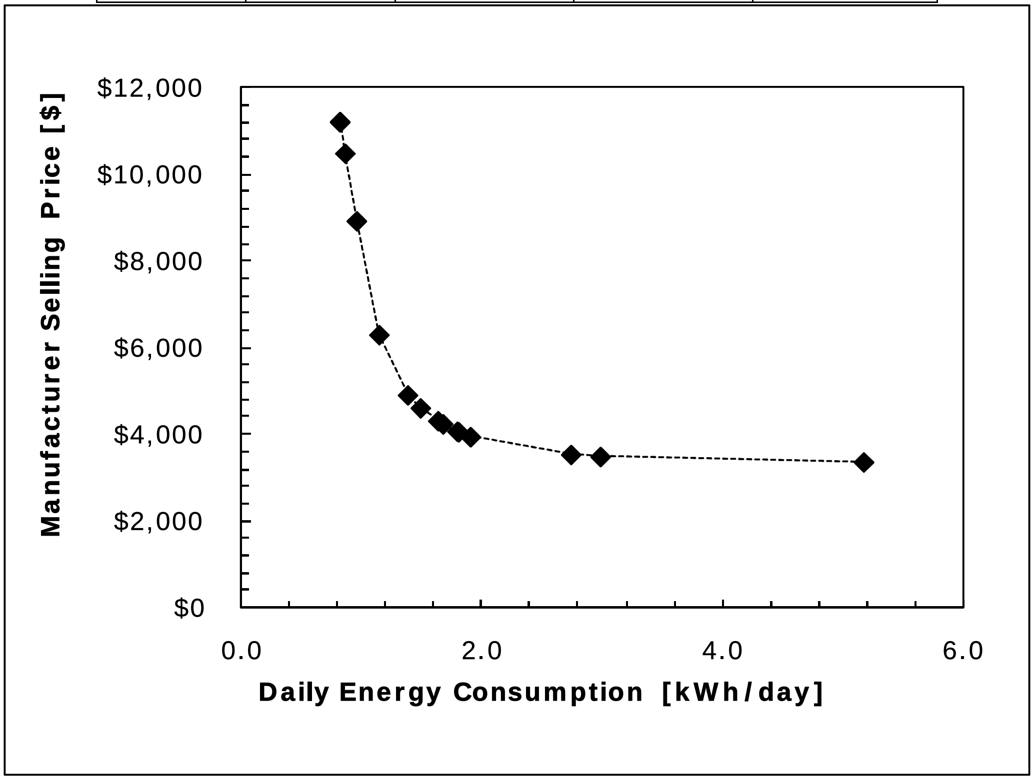

Figure 5.5.1 Cost-Efficiency Curve for the ND.C. Equipment Class [Small, Number of Doors: Display, Passage, and Freight (0,1,0)]

Table 5.5.2 Cost-Efficiency Data for the ND.C. Medium Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	11.50	$4,164	$6,476	Baseline
L1	6.13	$4,527	$6,981	L0 + SC
L2	5.88	$4,561	$7,028	L1 + LED
L3	5.85	$4,576	$7,049	L2 + XC
L4	4.38	$5,330	$8,291	L3 + FLR2
L5	4.14	$5,498	$8,551	L4 + TCK2
L6	3.86	$5,750	$8,941	L5 + TCK3
L7	3.73	$5,896	$9,159	L6 + FLR3
L8	3.38	$6,339	$9,841	L7 + TCK4
L9	3.13	$6,782	$10,523	L8 + TCK5
L10	2.55	$8,782	$13,303	L9 + VEST
L11	2.10	$13,381	$19,361	L10 + INSH1
L12	1.87	$15,961	$22,947	L11 + VIP
L13	1.76	$17,285	$24,788	L12 + ATG

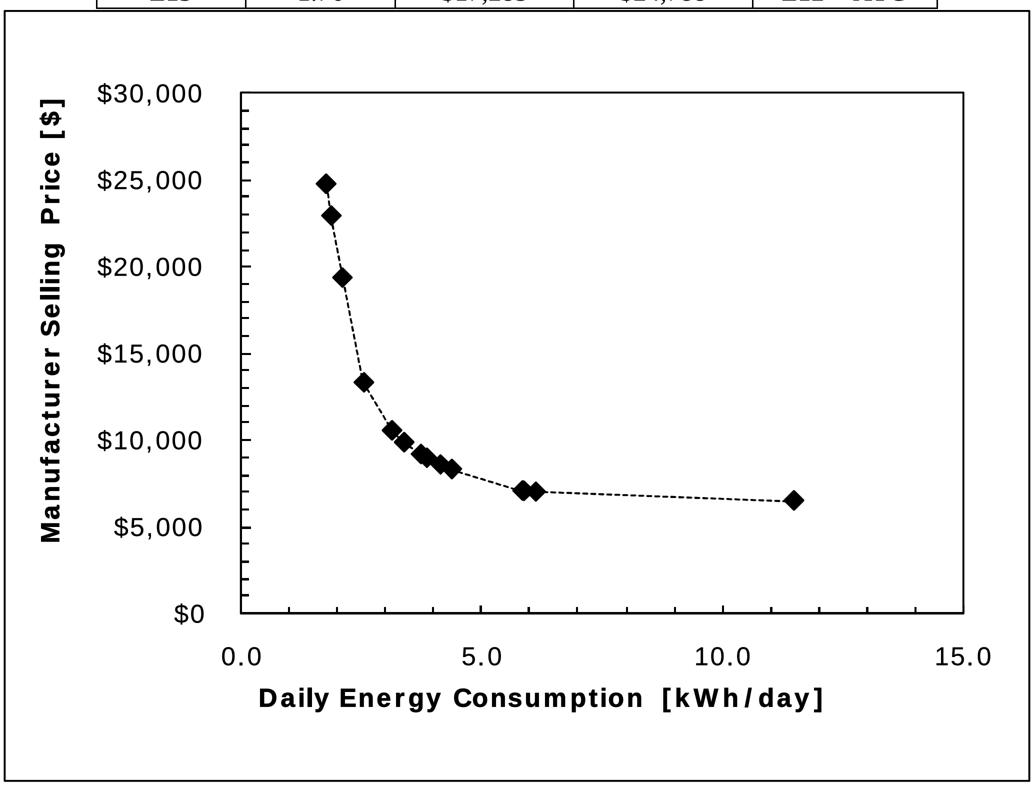

Figure 5.5.2 Cost-Efficiency Curve for the ND.C. Equipment Class [Medium, Number of Doors: Display, Passage, and Freight (0,1,1)]

Table 5.5.3 Cost-Efficiency Data for the ND.C. Large Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	23.55	$10,316	$16,069	Baseline
L1	14.27	$10,862	$16,827	L0 + SC
L2	13.53	$10,962	$16,967	L1 + LED
L3	13.45	$10,986	$17,000	L2 + XC
L4	12.88	$11,414	$17,655	L3 + TCK2
L5	12.19	$12,056	$18,637	L4 + TCK3
L6	9.80	$14,411	$22,541	L5 + FLR2
L7	9.42	$14,868	$23,227	L6 + FLR3
L8	9.22	$15,118	$23,574	L7 + CS2
L9	8.36	$16,246	$25,296	L8 + TCK4
L10	7.74	$17,373	$27,017	L9 + TCK5
L11	7.67	$17,573	$27,295	L10 + CS3
L12	6.73	$20,573	$31,465	L11 + VEST
L13	6.28	$24,020	$36,257	L12 + ATG
L14	5.18	$35,722	$51,745	L13 + INSH1
L15	4.62	$42,285	$60,868	L14 + VIP

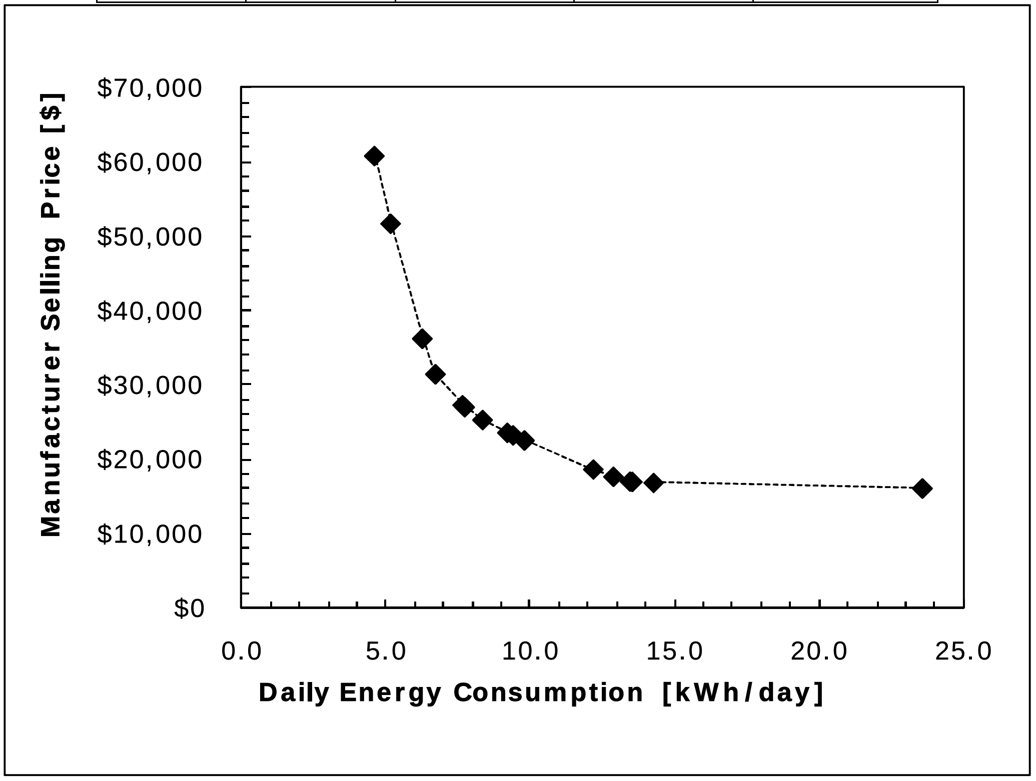

Figure 5.5.3 Cost-Efficiency Curve for the ND.C. Equipment Class [Large, Number of Doors: Display, Passage, and Freight (0,2,1)]

Table 5.5.4 Cost-Efficiency Data for the D.C. Small Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	34.65	$4,248	$6,036	Baseline
L1	28.53	$4,348	$6,175	L0 + ASCTRL
L2	23.40	$4,708	$6,675	L1 + LED
L3	19.56	$5,004	$7,086	L2 + SC
L4	13.69	$6,168	$8,704	L3 + DR2
L5	8.56	$7,204	$10,144	L4 + DR3
L6	8.03	$7,317	$10,326	L5 + FLR2
L7	7.16	$7,567	$10,673	L6 + CS2
L8	7.12	$7,595	$10,719	L7 + TCK2
L9	7.07	$7,636	$10,787	L8 + TCK3
L10	5.44	$9,206	$12,969	L9 + DR4
L11	5.43	$9,212	$12,978	L10 + XC
L12	5.41	$9,234	$13,010	L11 + FLR3
L13	5.35	$9,307	$13,129	L12 + TCK4
L14	5.31	$9,380	$13,249	L13 + TCK5
L15	5.23	$10,137	$14,210	L14 + INSH1

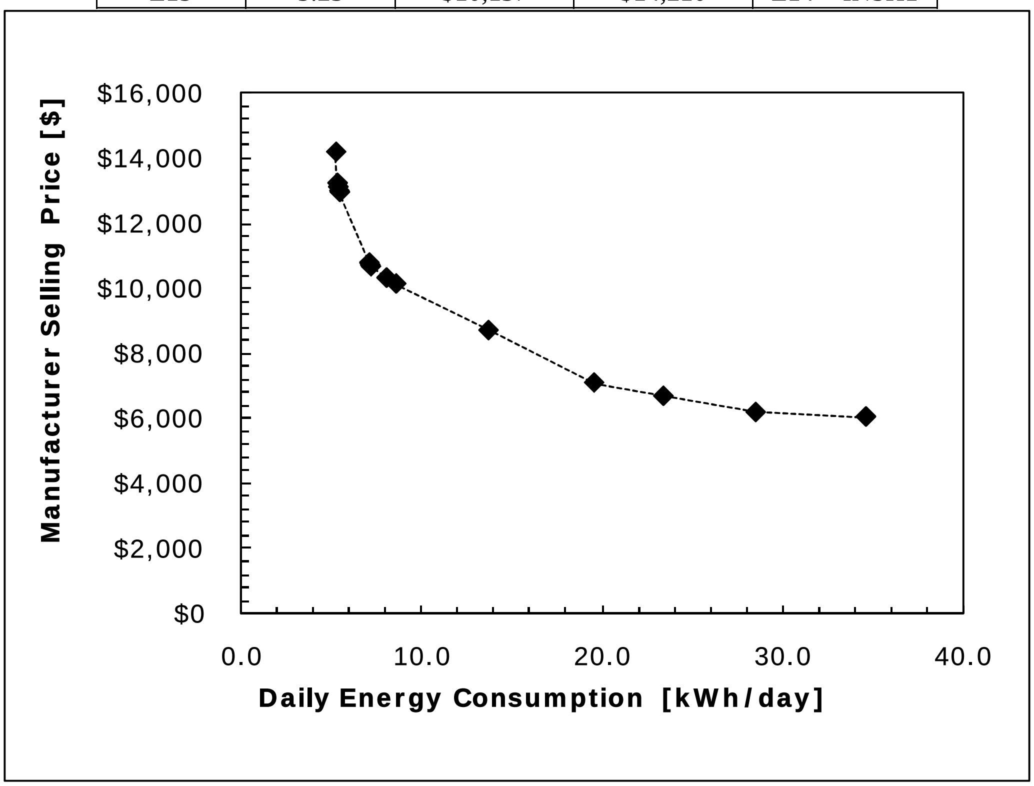

Figure 5.5.4 Cost-Efficiency Curve for the D.C. Equipment Class [Small, Number of Doors: Display, Passage, and Freight (3,1,0)]

Table 5.5.5 Cost-Efficiency Data for the D.C. Medium Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	85.84	$9,913	$14,028	Baseline
L1	69.52	$10,073	$14,250	L0 + ASCTRL
L2	60.76	$10,383	$14,681	L1 + CS2
L3	54.15	$11,019	$15,565	L2 + SC
L4	47.74	$11,919	$16,817	L3 + LED
L5	32.09	$15,024	$21,133	L4 + DR2
L6	18.42	$17,893	$25,120	L5 + DR3
L7	17.64	$18,117	$25,485	L6 + FLR2
L8	17.58	$18,158	$25,553	L7 + TCK2
L9	17.57	$18,167	$25,566	L8 + XC
L10	17.50	$18,228	$25,668	L9 + TCK3
L11	13.13	$22,413	$31,486	L10 + DR4
L12	13.09	$22,457	$31,550	L11 + FLR3
L13	13.01	$22,565	$31,728	L12 + TCK4
L14	12.94	$22,673	$31,906	L13 + TCK5
L15	12.83	$23,791	$33,317	L14 + INSH1

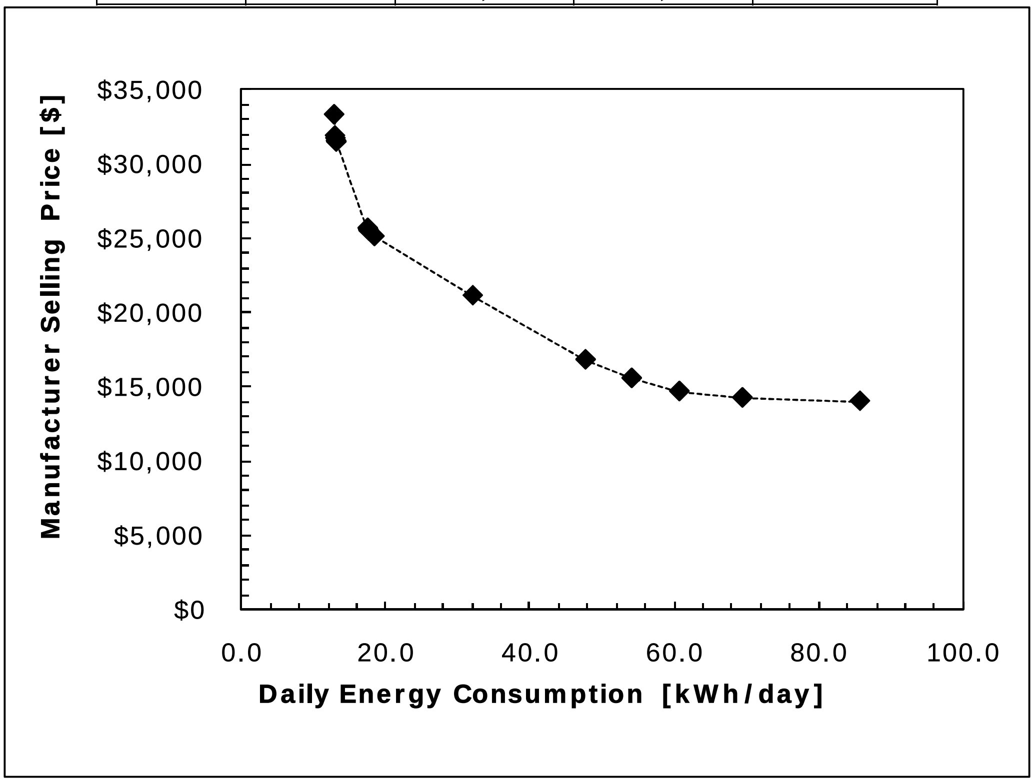

Figure 5.5.5 Cost-Efficiency Curve for the D.C. Equipment Class [Medium, Number of Doors: Display, Passage, and Freight (8,1,0)]

Table 5.5.6 Cost-Efficiency Data for the D.C. Large Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	409.07	$62,175	$88,642	Baseline
L1	363.04	$63,325	$90,240	L0 + CS2
L2	331.01	$66,916	$95,231	L1 + SC
L3	297.67	$71,596	$101,737	L2 + LED
L4	199.83	$91,002	$128,712	L3 + DR2
L5	114.43	$108,932	$153,634	L4 + DR3
L6	114.32	$108,960	$153,673	L5 + XC
L7	113.80	$109,359	$154,304	L6 + TCK2
L8	109.75	$113,127	$160,551	L7 + FLR2
L9	82.44	$139,284	$196,909	L8 + DR4
L10	81.81	$139,882	$197,859	L9 + TCK3
L11	81.19	$140,614	$198,957	L10 + FLR3
L12	80.43	$141,667	$200,616	L11 + TCK4
L13	79.87	$142,719	$202,275	L12 + TCK5
L14	79.84	$142,919	$202,553	L13 + CS3
L15	79.22	$147,623	$209,091	L14 + ATG

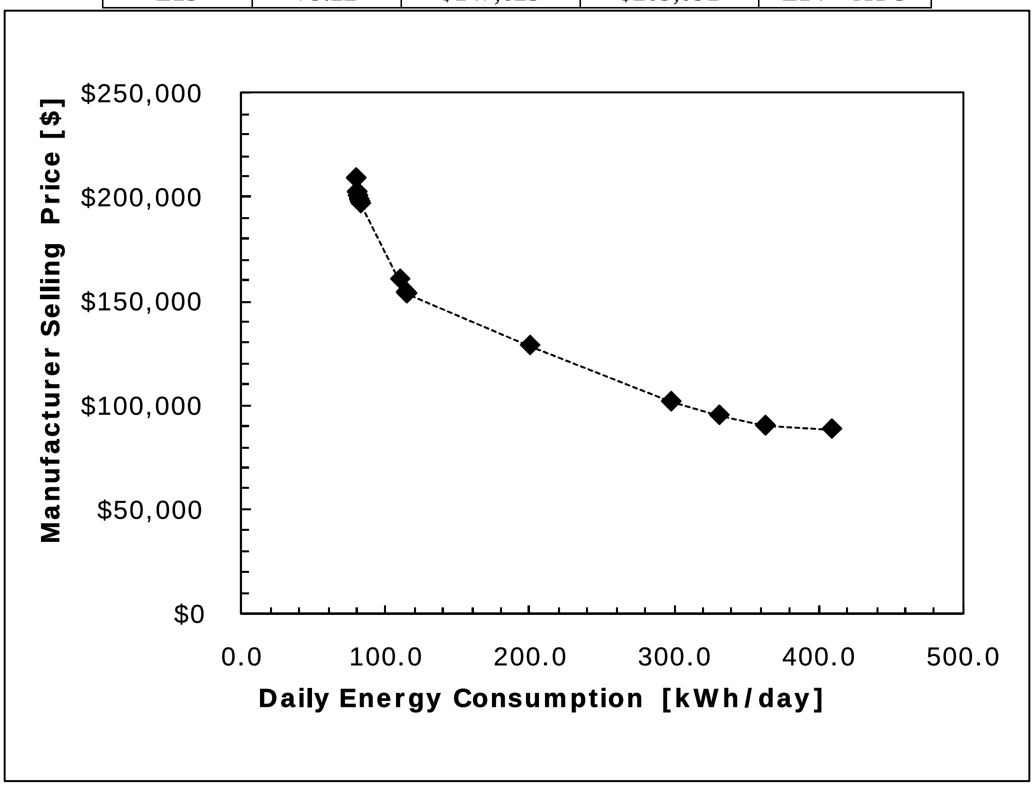

Figure 5.5.6 Cost-Efficiency Curve for the D.C. Equipment Class [Large, Number of Doors: Display, Passage, and Freight (50,2,0)]

Table 5.5.7 Cost-Efficiency Data for the ND.F. Small Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	25.67	$2,347	$3,484	Baseline
L1	13.12	$2,458	$3,638	L0 + SC
L2	12.82	$2,491	$3,685	L1 + LED
L3	12.52	$2,544	$3,767	L2 + TCK2
L4	12.16	$2,623	$3,891	L3 + TCK3
L5	12.12	$2,631	$3,902	L4 + XC
L6	12.01	$2,660	$3,945	L5 + FLR2
L7	11.56	$2,799	$4,161	L6 + TCK4
L8	11.48	$2,829	$4,204	L7 + FLR3
L9	11.15	$2,968	$4,420	L8 + TCK5
L10	10.26	$3,428	$5,060	L9 + AC
L11	9.69	$4,871	$6,950	L10 + INSH1
L12	9.39	$5,681	$8,076	L11 + VIP
L13	9.27	$6,053	$8,593	L12 + ATG
L14	8.99	$7,053	$9,983	L13 + VEST
L15	8.98	$7,303	$10,330	L14 + CS2

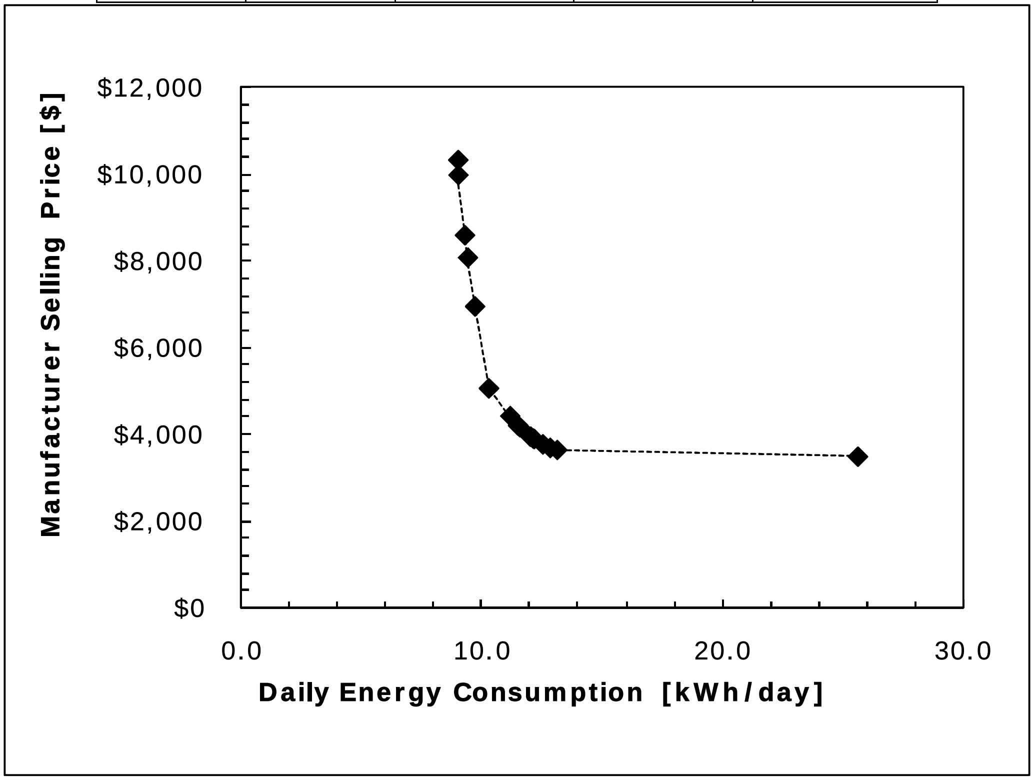

Figure 5.5.7 Cost-Efficiency Curve for the ND.F. Equipment Class [Small, Number of Doors: Display, Passage, and Freight (0,1,0)]

Table 5.5.8 Cost-Efficiency Data for the ND.F. Medium Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	55.25	$5,818	$8,821	Baseline
L1	24.40	$6,262	$9,437	L0 + SC
L2	24.10	$6,295	$9,484	L1 + LED
L3	24.00	$6,309	$9,503	L2 + XC
L4	23.15	$6,452	$9,724	L3 + TCK2
L5	22.13	$6,665	$10,055	L4 + TCK3
L6	21.70	$6,775	$10,218	L5 + FLR2
L7	20.44	$7,150	$10,797	L6 + TCK4
L8	20.15	$7,260	$10,961	L7 + FLR3
L9	17.86	$8,180	$12,239	L8 + AC
L10	16.95	$8,555	$12,818	L9 + TCK5
L11	15.33	$12,450	$17,941	L10 + INSH1
L12	14.51	$14,634	$20,977	L11 + VIP
L13	13.84	$16,634	$23,757	L12 + VEST
L14	13.47	$17,742	$25,297	L13 + ATG
L15	13.46	$17,992	$25,645	L14 + CS2

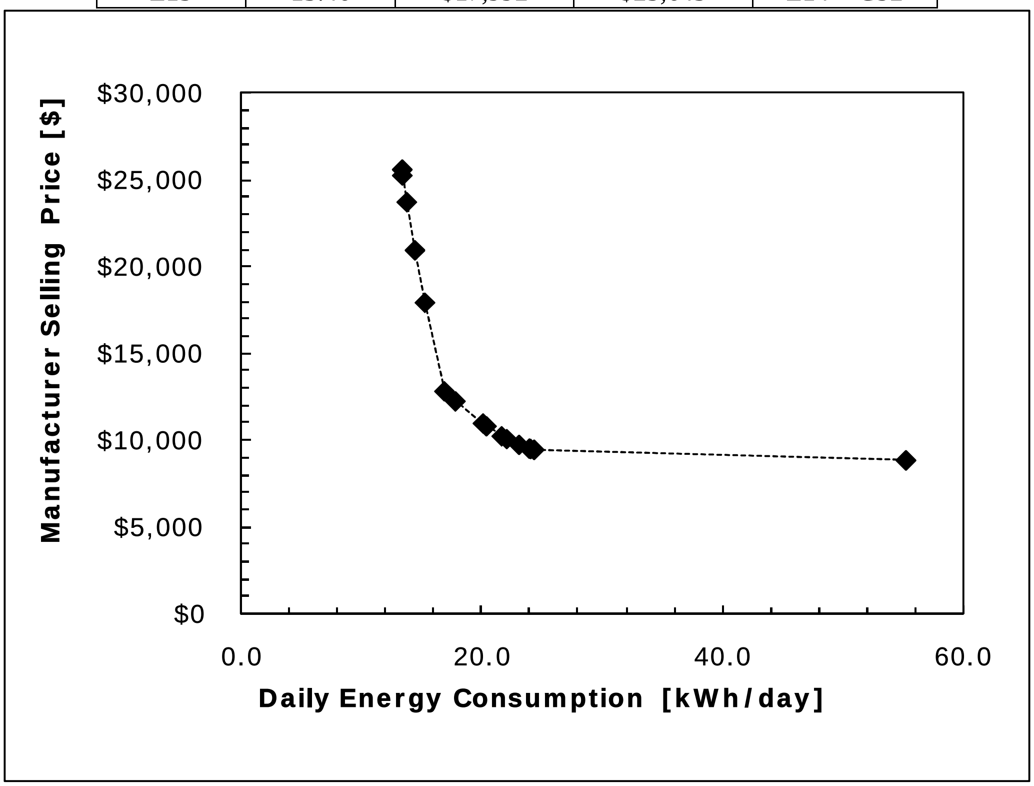

Figure 5.5.8 Cost-Efficiency Curve for the ND.F. Equipment Class [Medium, Number of Doors: Display, Passage, and Freight (0,1,1)]

Table 5.5.9 Cost-Efficiency Data for the ND.F. Large Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	105.04	$13,130	$19,978	Baseline
L1	51.78	$13,796	$20,903	L0 + SC
L2	51.54	$13,817	$20,932	L1 + XC
L3	50.65	$13,917	$21,072	L2 + LED
L4	48.82	$14,237	$21,564	L3 + TCK2
L5	46.61	$14,717	$22,302	L4 + TCK3
L6	45.42	$15,022	$22,759	L5 + FLR2
L7	42.69	$15,865	$24,050	L6 + TCK4
L8	38.63	$17,245	$25,968	L7 + AC
L9	37.83	$17,550	$26,425	L8 + FLR3
L10	35.87	$18,393	$27,715	L9 + TCK5
L11	35.60	$18,643	$28,063	L10 + CS2
L12	34.25	$21,183	$31,593	L11 + ATG
L13	34.16	$21,383	$31,871	L12 + CS3
L14	30.67	$30,135	$43,437	L13 + INSH1
L15	28.88	$35,044	$50,260	L14 + VIP

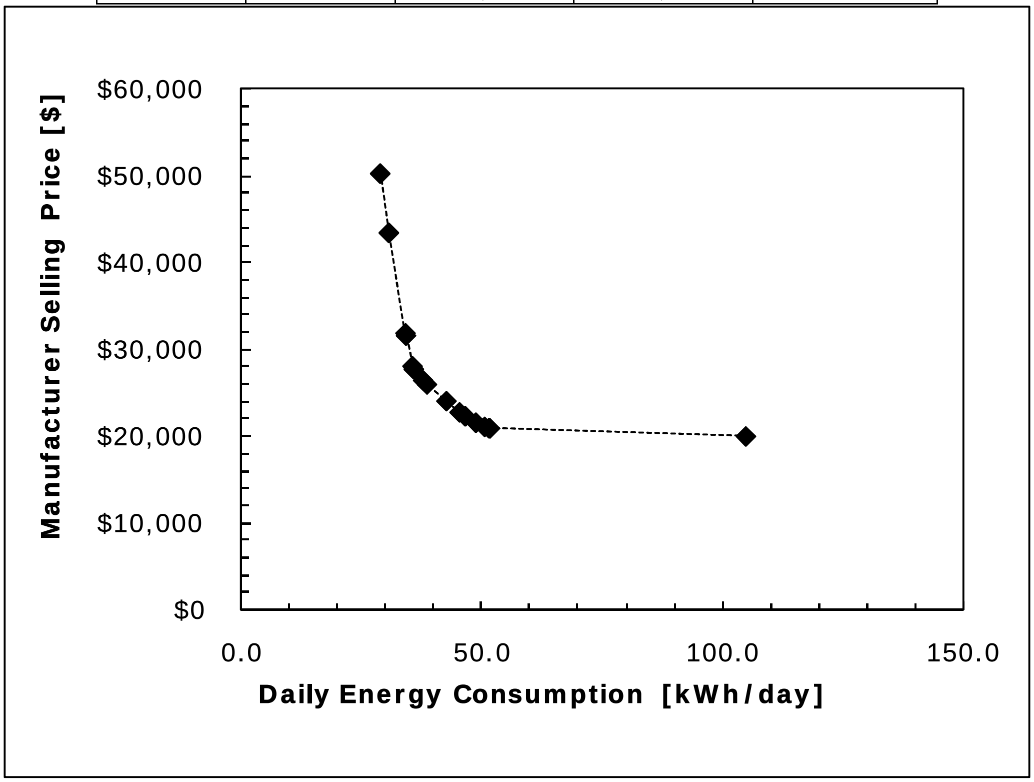

Figure 5.5.9 Cost-Efficiency Curve for the ND.F. Equipment Class [Large, Number of Doors: Display, Passage, and Freight (0,2,1)]

Table 5.5.10 Cost-Efficiency Data for the D.F. Small Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	79.22	$5,016	$7,127	Baseline
L1	68.74	$5,116	$7,266	L0 + ASCTRL
L2	46.66	$5,476	$7,767	L1 + SC
L3	40.46	$5,836	$8,267	L2 + LED
L4	40.29	$5,864	$8,313	L3 + TCK2
L5	34.76	$6,780	$9,586	L4 + DR2
L6	24.70	$8,503	$11,981	L5 + DR3
L7	24.49	$8,544	$12,049	L6 + TCK3
L8	23.42	$8,794	$12,397	L7 + CS2
L9	23.34	$8,816	$12,429	L8 + FLR2
L10	23.31	$8,823	$12,438	L9 + XC
L11	23.06	$8,896	$12,558	L10 + TCK4
L12	19.57	$10,116	$14,253	L11 + DR4
L13	19.52	$10,138	$14,285	L12 + FLR3
L14	19.33	$10,211	$14,404	L13 + TCK5
L15	17.84	$12,051	$16,962	L14 + AC

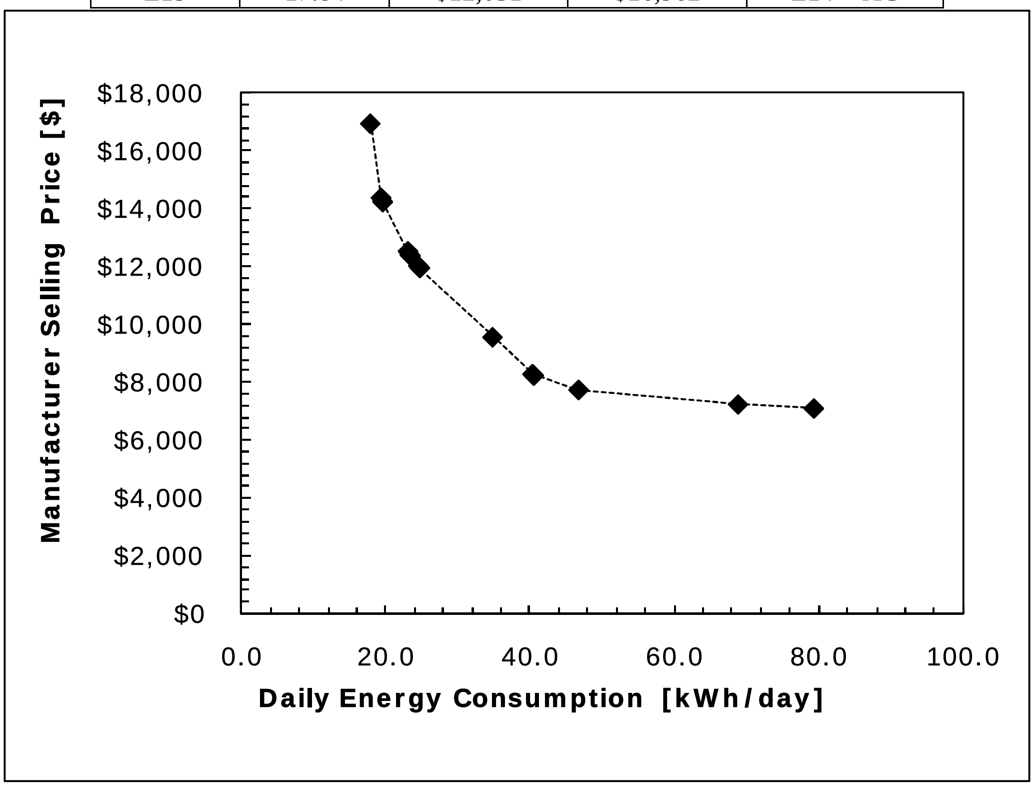

Figure 5.5.10 Cost-Efficiency Curve for the D.F. Equipment Class [Small, Number of Doors: Display, Passage, and Freight (3,1,0)]

Table 5.5.11 Cost-Efficiency Data for the D.F. Medium Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	170.22	$11,510	$16,301	Baseline
L1	142.26	$11,670	$16,523	L0 + ASCTRL
L2	104.31	$12,446	$17,602	L1 + SC
L3	94.77	$12,756	$18,033	L2 + CS2
L4	87.80	$13,566	$19,159	L3 + LED
L5	73.05	$16,010	$22,556	L4 + DR2
L6	72.81	$16,051	$22,624	L5 + TCK2
L7	45.97	$20,751	$29,157	L6 + DR3
L8	45.93	$20,760	$29,170	L7 + XC
L9	45.64	$20,821	$29,272	L8 + TCK3
L10	45.47	$20,865	$29,336	L9 + FLR2
L11	45.11	$20,972	$29,514	L10 + TCK4
L12	35.82	$24,225	$34,035	L11 + DR4
L13	35.71	$24,269	$34,100	L12 + FLR3
L14	35.45	$24,376	$34,278	L13 + TCK5
L15	32.94	$28,516	$40,032	L14 + AC

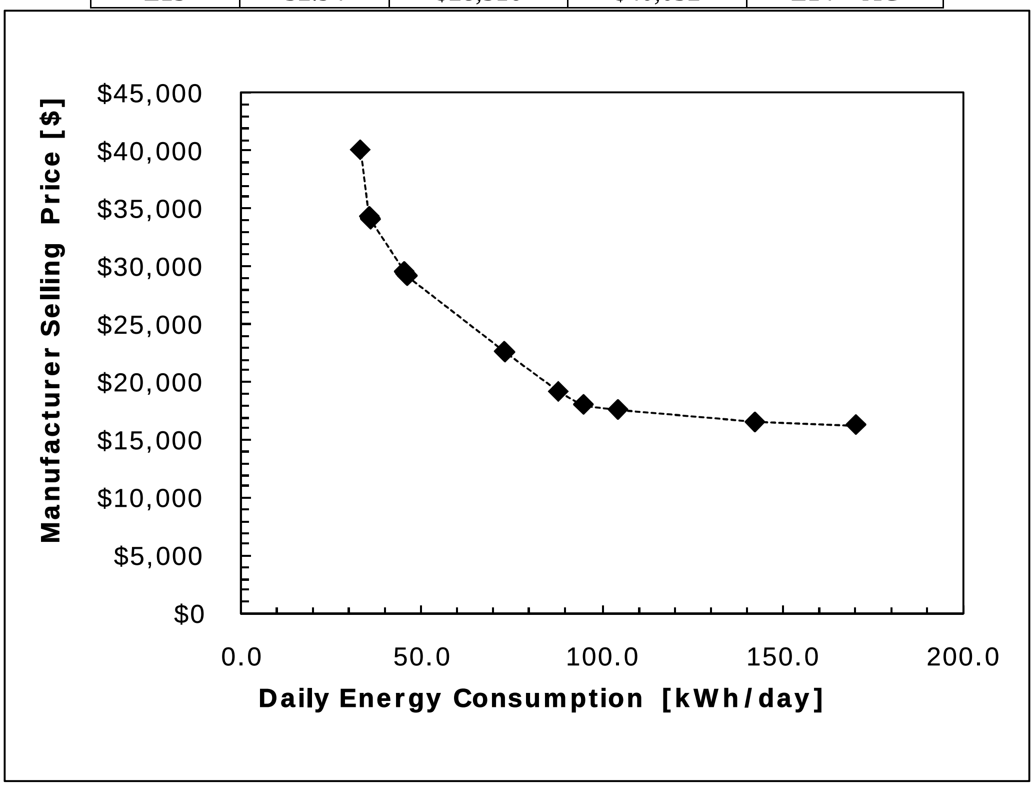

Figure 5.5.11 Cost-Efficiency Curve for the D.F. Equipment Class [Medium, Number of Doors: Display, Passage, and Freight (8,1,0)]

Table 5.5.12 Cost-Efficiency Data for the D.F. Large Equipment Class

Efficiency Level	Daily Energy Use [kWh/day]	MPC Mfg. Cost [$]	MSP Mfg. Price [$]	Design Option
L0	811.05	$79,357	$113,532	Baseline
L1	755.37	$80,507	$115,131	L0 + CS2
L2	571.53	$84,888	$121,220	L1 + SC
L3	571.09	$84,916	$121,259	L2 + XC
L4	530.78	$89,597	$127,765	L3 + LED
L5	438.61	$104,870	$148,995	L4 + DR2
L6	270.88	$134,245	$189,826	L5 + DR3
L7	268.73	$134,644	$190,460	L6 + TCK2
L8	266.13	$135,243	$191,410	L7 + TCK3
L9	263.28	$135,975	$192,508	L8 + FLR2
L10	260.07	$137,027	$194,167	L9 + TCK4
L11	202.02	$157,356	$222,424	L10 + DR4
L12	200.11	$158,088	$223,523	L11 + FLR3
L13	197.80	$159,140	$225,182	L12 + TCK5
L14	197.60	$159,340	$225,460	L13 + CS3
L15	195.10	$164,044	$231,998	L14 + ATG

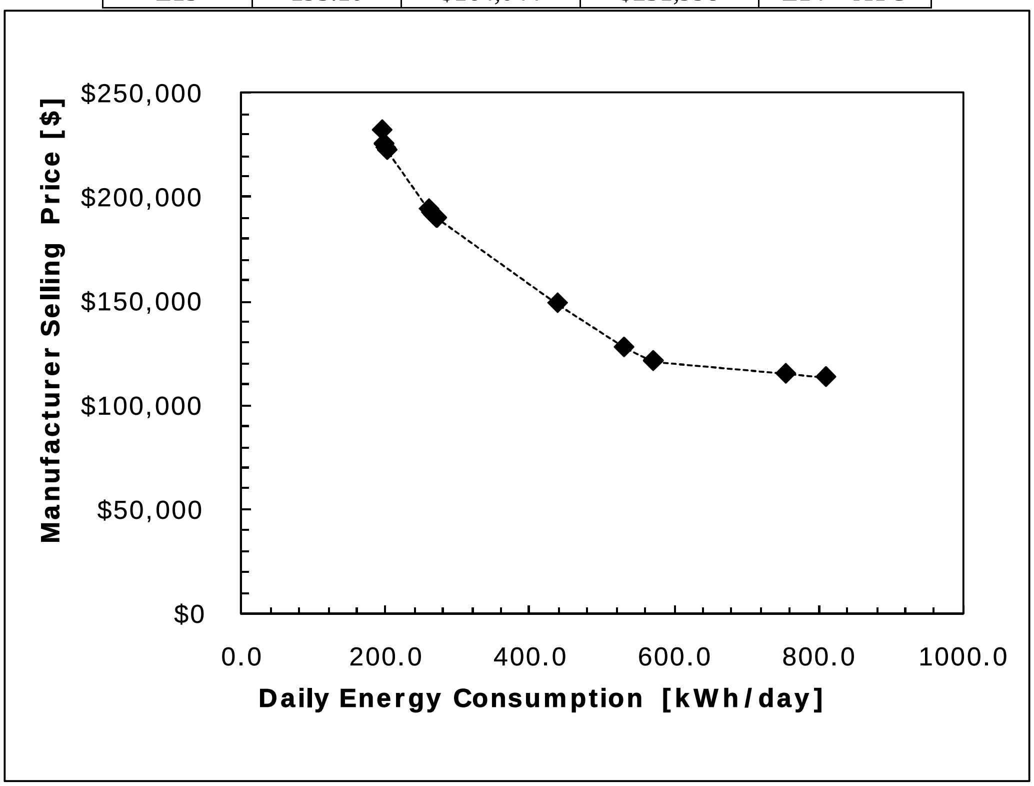

Figure 5.5.12 Cost-Efficiency Curve for the D.F. Equipment Class [Large, Number of Doors: Display, Passage, and Freight (50,2,0)]

5.5.2 Refrigeration Cost-Efficiency Curves

Table 5.5.13 Cost-Efficiency Data for the DC.M.I Equipment Class (Small)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	1.96	$1,923	$163	$2,710	$229	-
L1	1.53	$1,999	$137	$2,828	$194	L0 + CD2
L2	1.46	$2,038	$133	$2,886	$189	L1 + EV2
L3	1.33	$2,109	$138	$2,985	$195	L2 + ECM
L4	1.08	$2,409	$158	$3,402	$223	L3 + EM2
L5	1.06	$2,427	$159	$3,427	$224	L4 + CB2
L6	1.03	$2,511	$163	$3,544	$230	L5 + EB2
L7	0.98	$2,505	$193	$3,535	$273	L6 + SCR

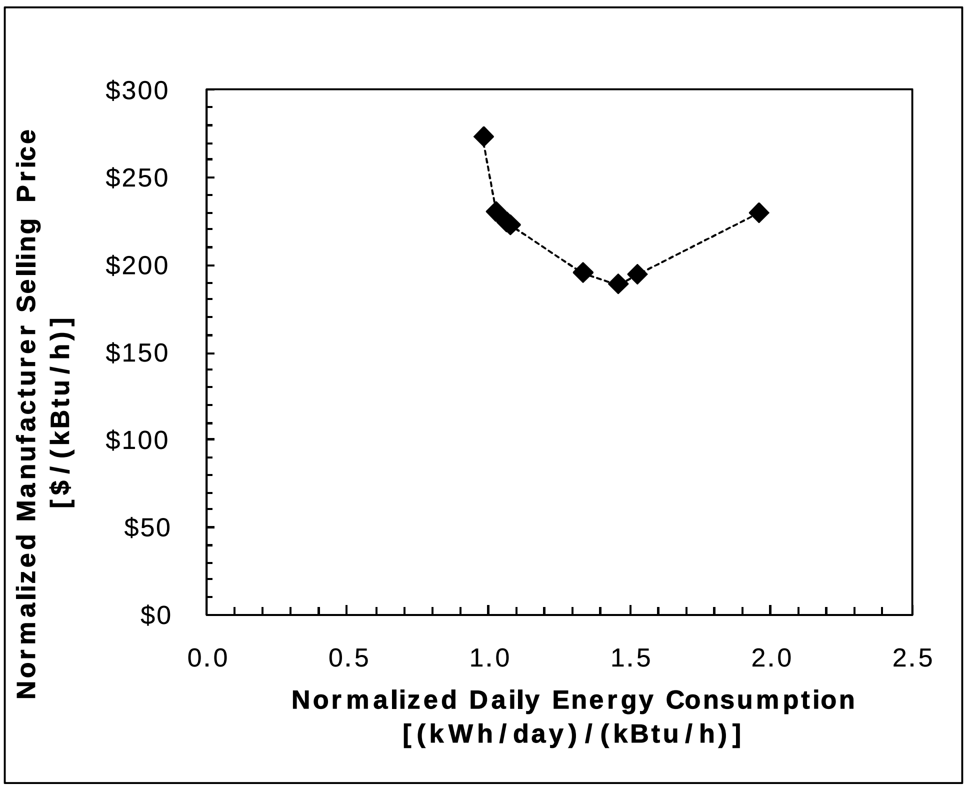

Figure 5.5.13 Cost-Efficiency Curve for the DC.M.I Equipment Class (Small)

Table 5.5.14 Cost-Efficiency Data for the DC.M.I Equipment Class (Large)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/ (kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	1.87	$2,613	$124	$3,696	$176	-
L1	1.79	$2,664	$121	$3,772	$171	L0 + EV2
L2	1.41	$2,812	$105	$4,006	$149	L1 + CD2
L3	1.26	$2,954	$110	$4,204	$157	L2 + ECM
L4	1.02	$3,254	$121	$4,621	$172	L3 + EM2
L5	1.01	$3,291	$123	$4,672	$174	L4 + CB2
L6	0.97	$3,431	$127	$4,866	$180	L5 + EB2
L7	0.94	$3,705	$153	$5,247	$217	L6 + SCR

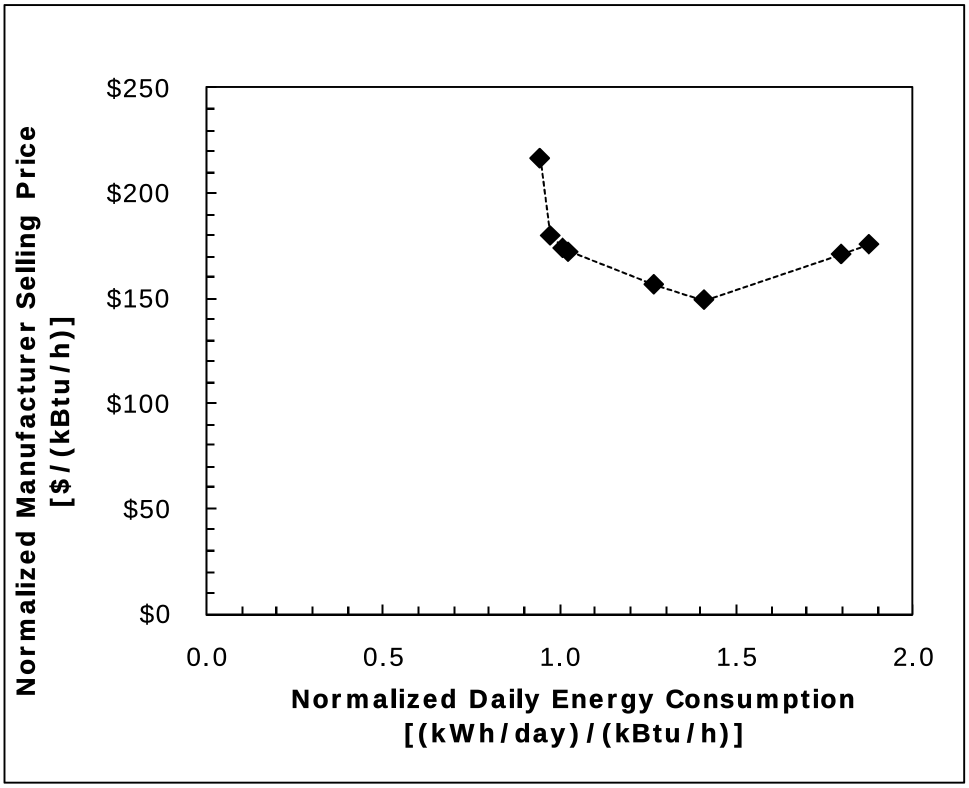

Figure 5.5.14 Cost-Efficiency Curve for the DC.M.I Equipment Class (Large)

Table 5.5.15 Cost-Efficiency Data for the DC.M.O Equipment Class (Small)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	1.59	$2,194	$154	$3,102	$217	-
L1	1.51	$2,221	$147	$3,142	$208	L0 + EV2
L2	1.25	$2,412	$137	$3,436	$195	L1 + CD2
L3	0.87	$2,612	$149	$3,714	$211	L2 + FHP
L4	0.81	$2,683	$153	$3,813	$217	L3 + ECM
L5	0.73	$2,992	$157	$4,242	$223	L4 + SCR
L6	0.67	$3,076	$161	$4,359	$228	L5 + EB2
L7	0.50	$3,376	$176	$4,776	$249	L6 + EM2

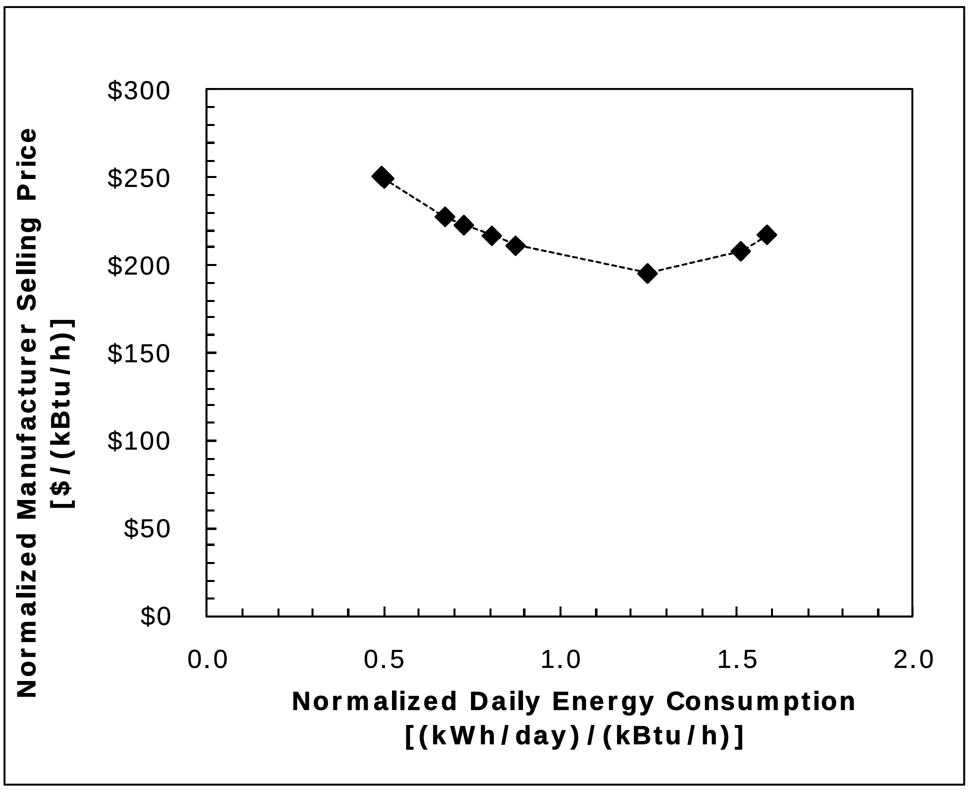

Figure 5.5.15 Cost-Efficiency Curve for the DC.M.O Equipment Class (Small)

Table 5.5.16 Cost-Efficiency Data for the DC.M.O Equipment Class (Large)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	1.70	$2,689	$128	$3,801	$181	-
L1	1.63	$2,725	$124	$3,856	$175	L0 + EV2
L2	1.46	$2,999	$117	$4,237	$165	L1 + SCR
L3	1.22	$3,190	$113	$4,530	$160	L2 + CD2
L4	0.88	$3,390	$120	$4,808	$170	L3 + FHP
L5	0.64	$3,690	$130	$5,225	$185	L4 + EM2
L6	0.56	$3,833	$135	$5,423	$192	L5 + ECM
L7	0.55	$3,869	$137	$5,474	$193	L6 + CB2
L8	0.52	$4,009	$141	$5,669	$199	L7 + EB2

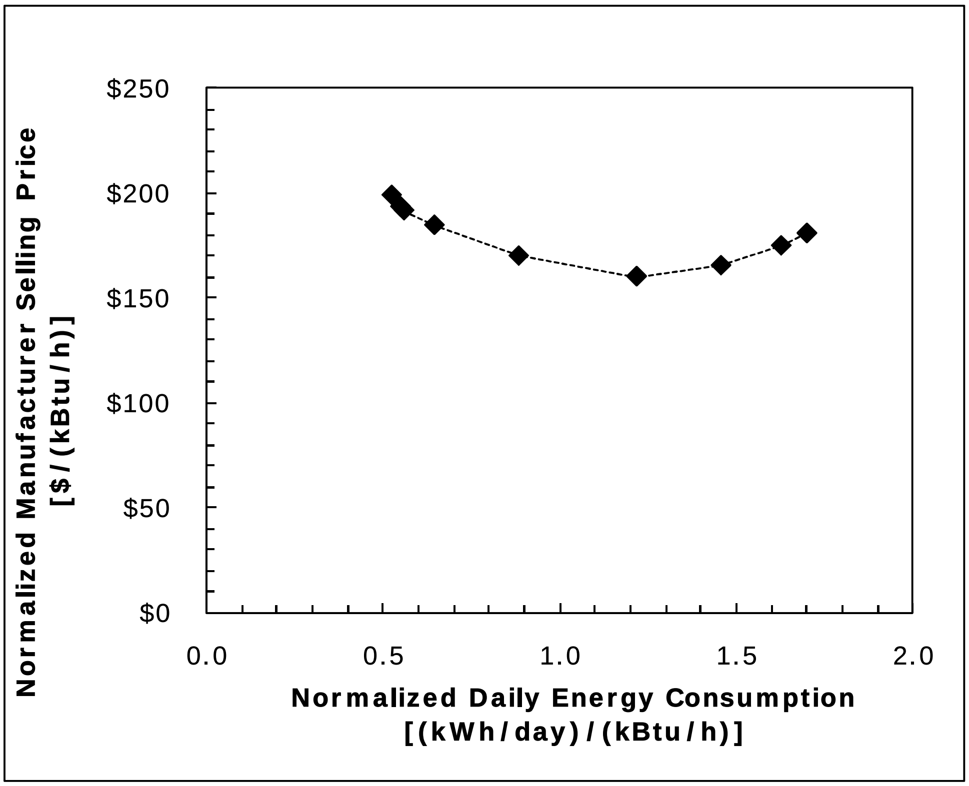

Figure 5.5.16 Cost-Efficiency Curve for the DC.M.O Equipment Class (Large)

Table 5.5.17 Cost-Efficiency Data for the MC.M.I Equipment Class (Small)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/ (kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	1.08	$ 729	$ 79	$1,029	$112	-
L1	1.00	$ 739	$ 80	$1,043	$113	L0 + EB2
L2	0.98	$ 753	$ 81	$1,063	$115	L1 + EV2
L3	0.76	$1,053	$114	$1,480	$160	L2 + EM2

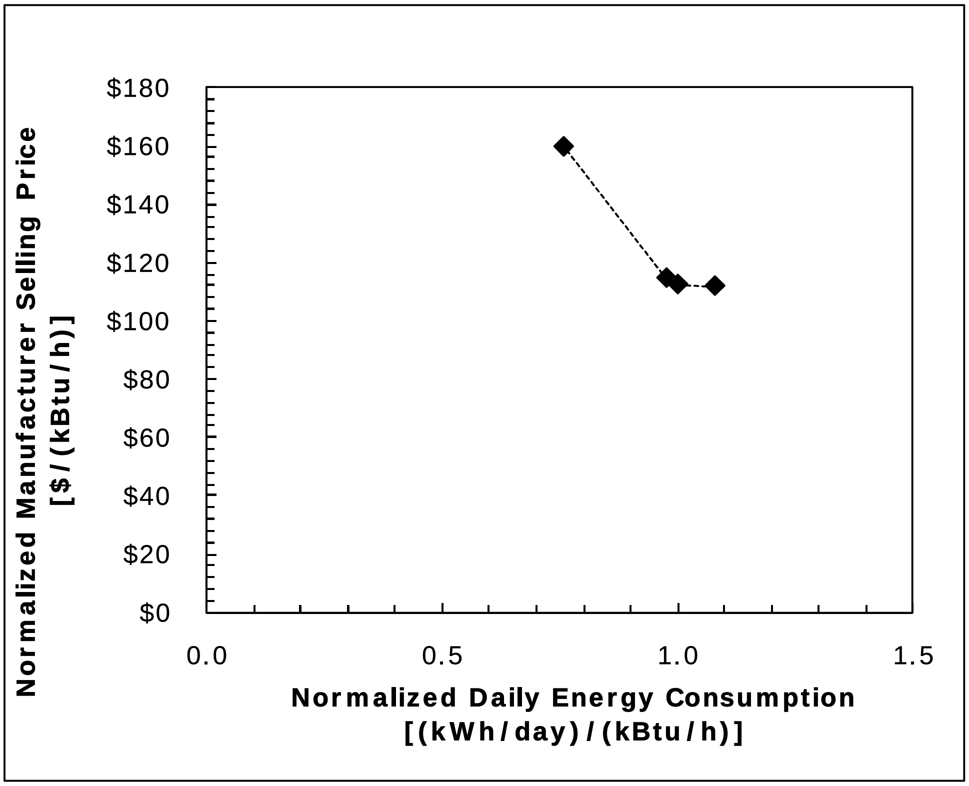

Figure 5.5.17 Cost-Efficiency Curve for the MC.M.I Equipment Class (Small)

Table 5.5.18 Cost-Efficiency Data for the MC.M.I Equipment Class (Large)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	1.04	$1,617	$ 55	$2,288	$ 77	-
L1	0.97	$1,648	$ 55	$2,329	$ 78	L0 + EB2
L2	0.95	$1,674	$ 56	$2,371	$ 79	L1 + EV2
L3	0.74	$1,974	$ 66	$2,788	$ 93	L2 + EM2

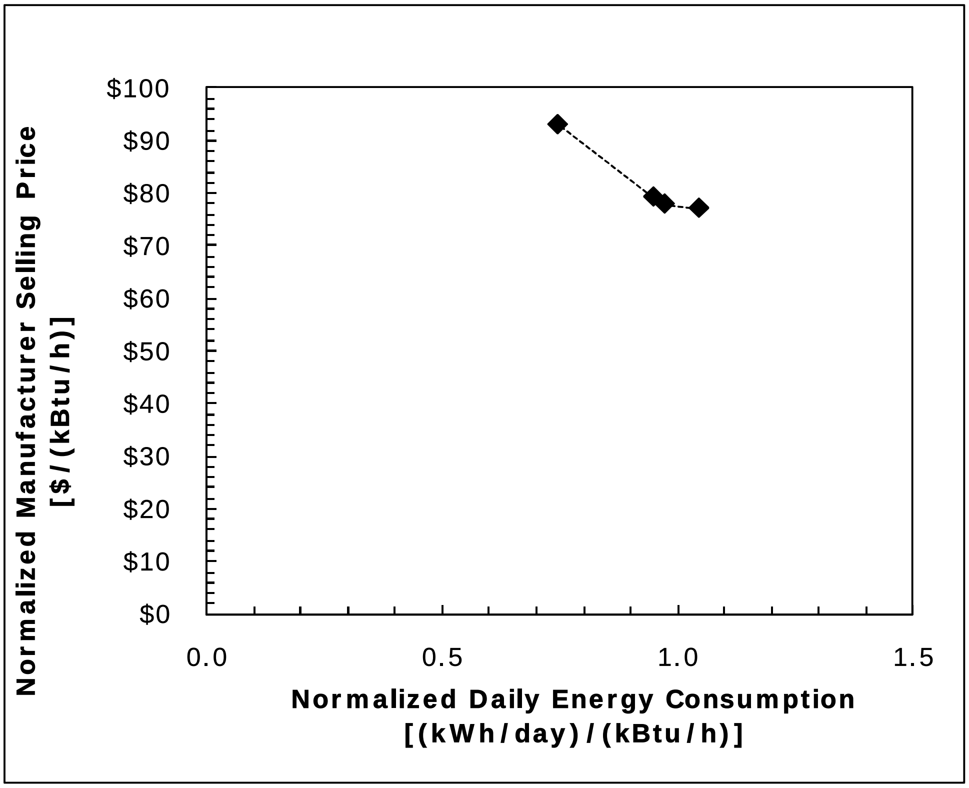

Figure 5.5.18 Cost-Efficiency Curve for the MC.M.I Equipment Class (Large)

Table 5.5.19 Cost-Efficiency Data for the DC.L.I Equipment Class (Small)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	6.60	$1,723	$349	$2,424	$491	-
L1	6.14	$1,751	$323	$2,465	$455	L0 + EV2
L2	5.37	$2,046	$290	$2,876	$408	L1 + SCR
L3	4.58	$2,143	$279	$3,022	$394	L2 + CD2
L4	4.14	$2,214	$288	$3,122	$407	L3 + ECM
L5	4.00	$2,270	$293	$3,199	$413	L4 + EB2
L6	3.95	$2,288	$295	$3,225	$416	L5 + CB2
L7	3.77	$2,473	$319	$3,482	$449	L6 + DF2
L8	3.53	$2,773	$358	$3,899	$503	L7 + EM2

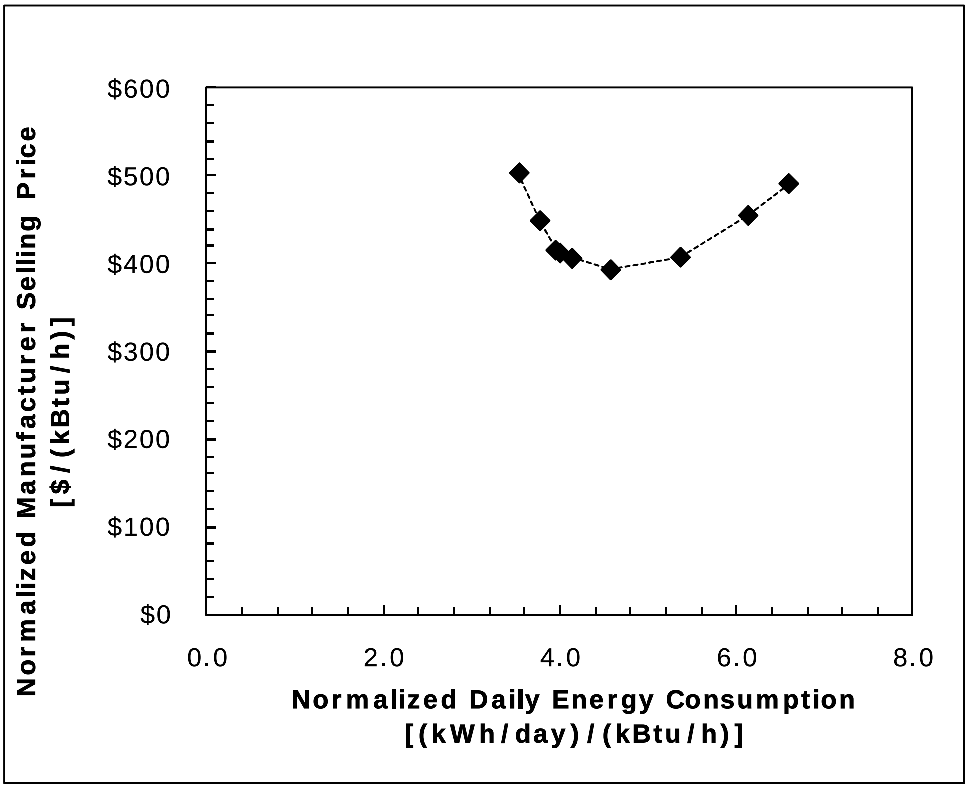

Figure 5.5.19 Cost-Efficiency Curve for the DC.L.I Equipment Class (Small)

Table 5.5.20 Cost-Efficiency Data for the DC.L.I Equipment Class (Large)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	6.01	$2,199	$222	$3,111	$314	-
L1	5.67	$2,226	$208	$3,153	$294	L0 + EV2
L2	4.78	$2,382	$189	$3,400	$270	L1 + CD2
L3	4.17	$2,672	$197	$3,802	$280	L2 + SCR
L4	3.67	$2,814	$207	$4,000	$295	L3 + ECM
L5	3.56	$2,898	$212	$4,117	$301	L4 + EB2
L6	3.50	$2,935	$214	$4,168	$304	L5 + CB2
L7	3.34	$3,120	$228	$4,425	$323	L6 + DF2
L8	3.15	$3,420	$250	$4,842	$354	L7 + EM2

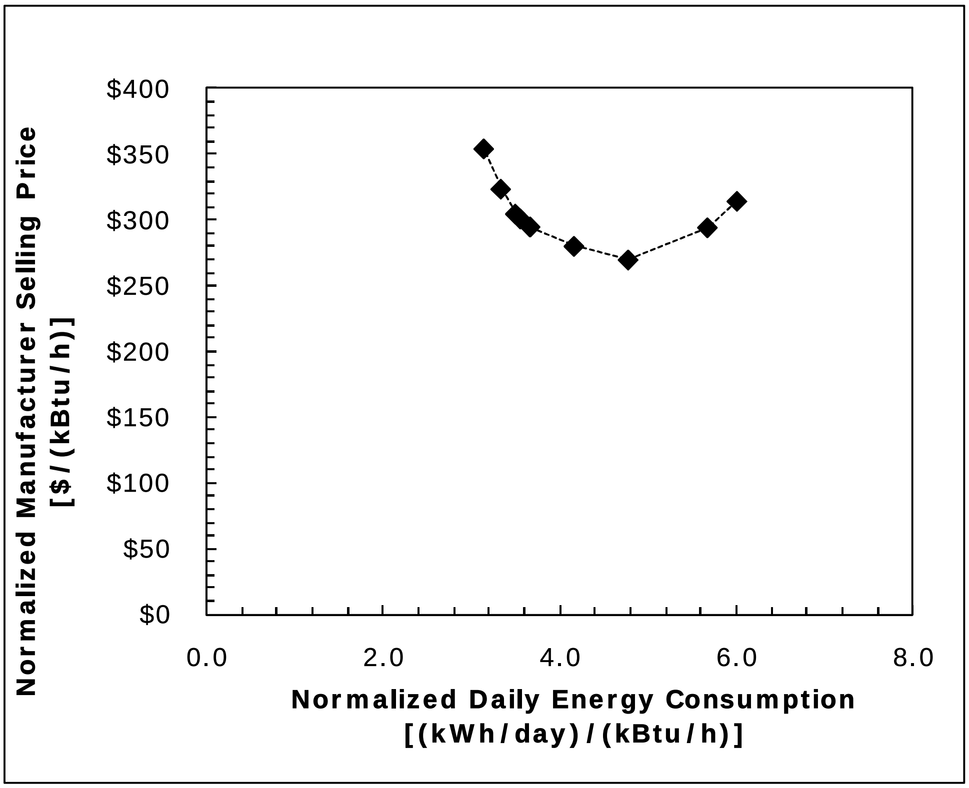

Figure 5.5.20 Cost-Efficiency Curve for the DC.L.I Equipment Class (Large)

Table 5.5.21 Cost-Efficiency Data for the DC.L.O Equipment Class (Small)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	5.81	$1,778	$360	$2,501	$506	-
L1	5.39	$1,795	$331	$2,525	$466	L0 + EV2
L2	4.67	$2,090	$296	$2,936	$416	L1 + SCR
L3	4.13	$2,207	$293	$3,111	$414	L2 + CD2
L4	3.75	$2,278	$303	$3,210	$427	L3 + ECM
L5	2.88	$2,478	$329	$3,488	$464	L4 + FHP
L6	2.76	$2,534	$333	$3,566	$469	L5 + EB2
L7	2.72	$2,553	$336	$3,592	$473	L6 + CB2
L8	2.44	$2,853	$375	$4,009	$527	L7 + EM2
L9	2.27	$3,038	$400	$4,266	$561	L8 + DF2

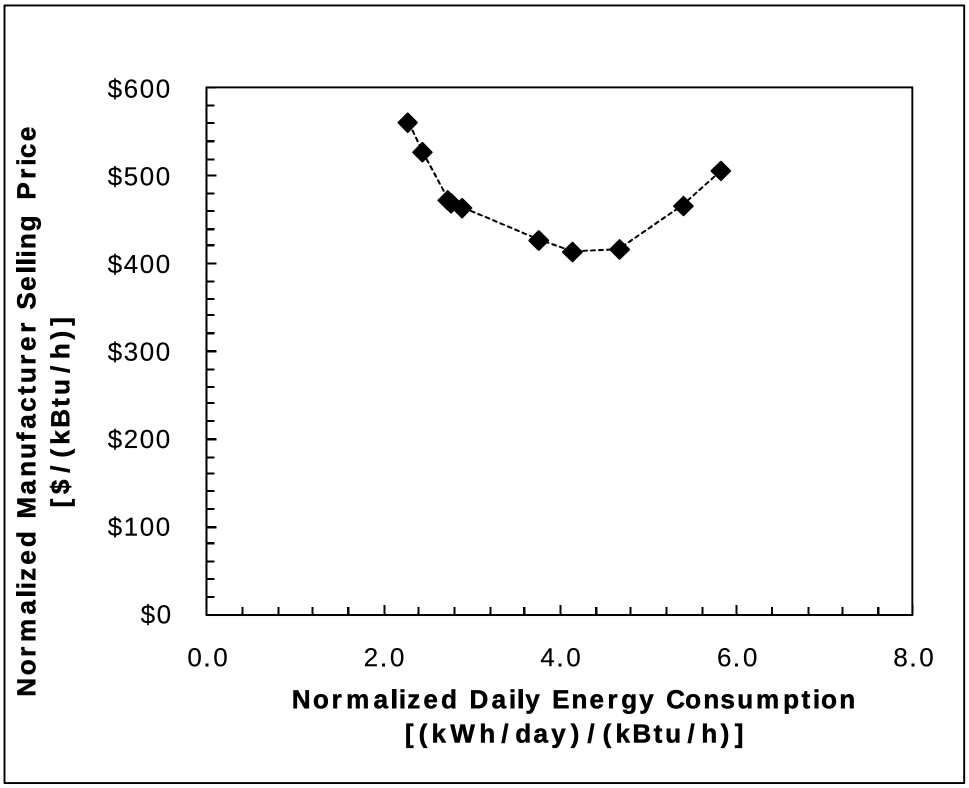

Figure 5.5.21 Cost-Efficiency Curve for the DC.L.O Equipment Class (Small)

Table 5.5.22 Cost-Efficiency Data for the DC.L.O Equipment Class (Large)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/ (kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	5.23	$2,281	$230	$3,225	$326	-
L1	4.93	$2,302	$215	$3,257	$304	L0 + EV2
L2	4.21	$2,591	$208	$3,659	$293	L1 + SCR
L3	3.74	$2,793	$210	$3,971	$298	L2 + CD2
L4	2.85	$2,993	$225	$4,249	$319	L3 + FHP
L5	2.49	$3,136	$236	$4,447	$334	L4 + ECM
L6	2.39	$3,220	$240	$4,564	$340	L5 + EB2
L7	2.35	$3,257	$243	$4,614	$344	L6 + CB2
L8	2.20	$3,442	$256	$4,872	$363	L7 + DF2
L9	1.96	$3,742	$279	$5,289	$394	L8 + EM2

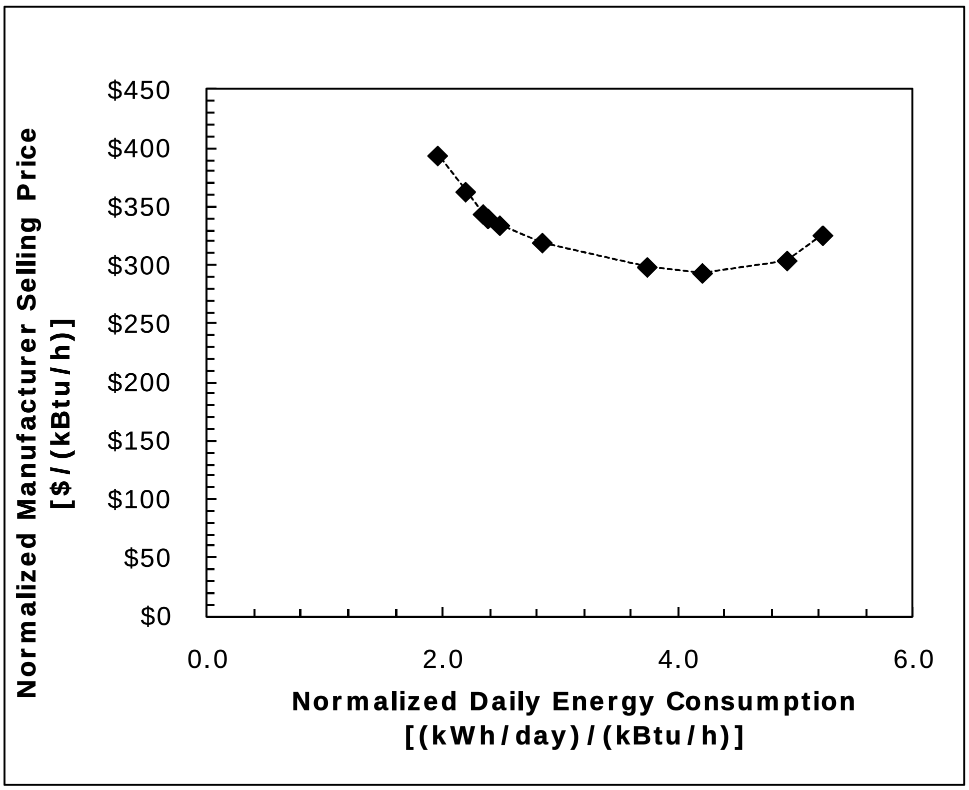

Figure 5.5.22 Cost-Efficiency Curve for the DC.L.O Equipment Class (Large)

Table 5.5.23 Cost-Efficiency Data for the MC.L.I Equipment Class (Small)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	3.35	$ 706	$118	$ 996	$166	-
L1	3.28	$ 718	$120	$1,014	$169	L0 + EV2
L2	3.13	$ 774	$128	$1,091	$180	L1 + EB2
L3	2.93	$ 959	$158	$1,349	$222	L2 + DF2
L4	2.68	$1,259	$208	$1,766	$291	L3 + EM2

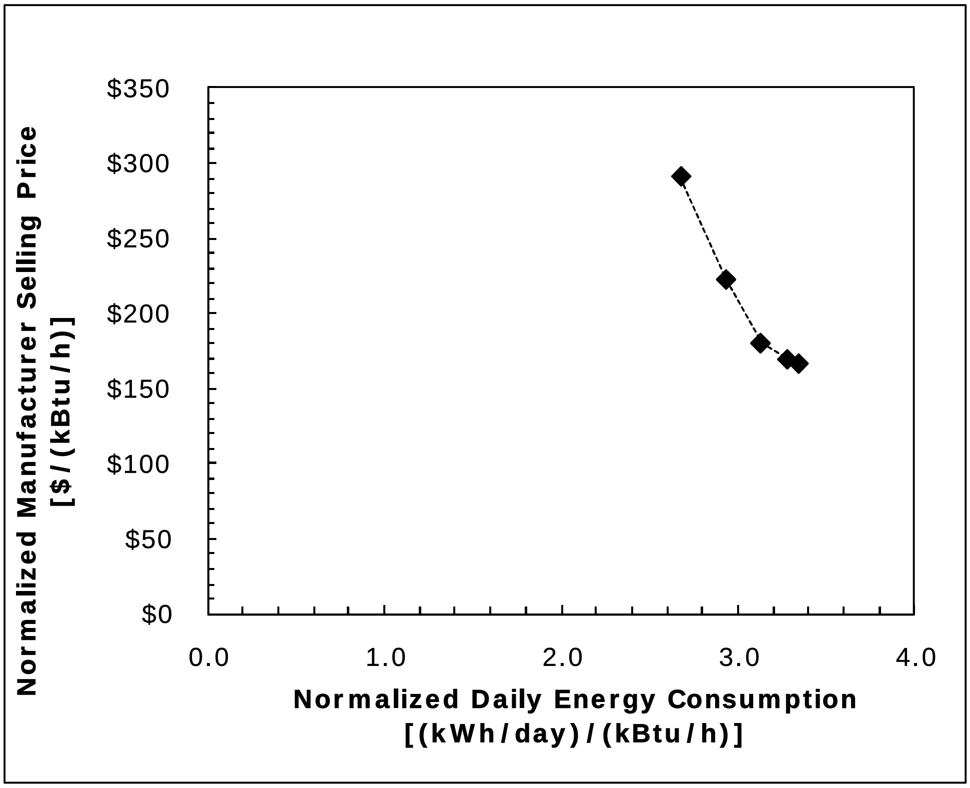

Figure 5.5.23 Cost-Efficiency Curve for the MC.L.I Equipment Class (Small)

Table 5.5.24 Cost-Efficiency Data for the MC.L.I Equipment Class (Large)

Efficiency Level*	Normalized Daily Energy Consumption [(kWh/day)/(kBtu/h)]	Manufacturer Production Cost (MPC) [$]	Normalized MPC [$/(kWh/day)]	Manufacturer Selling Price (MSP) [$]	Normalized MSP [$/(kBtu/h)]	Option
L0	2.96	$1,596	$ 60	$2,257	$ 85	-
L1	2.90	$1,619	$ 61	$2,293	$ 87	L0 + EV2
L2	2.74	$1,804	$ 68	$2,550	$ 96	L1 + DF2
L3	2.53	$2,104	$ 80	$2,967	$112	L2 + EM2
L4	2.47	$2,272	$ 85	$3,200	$120	L3 + EB2

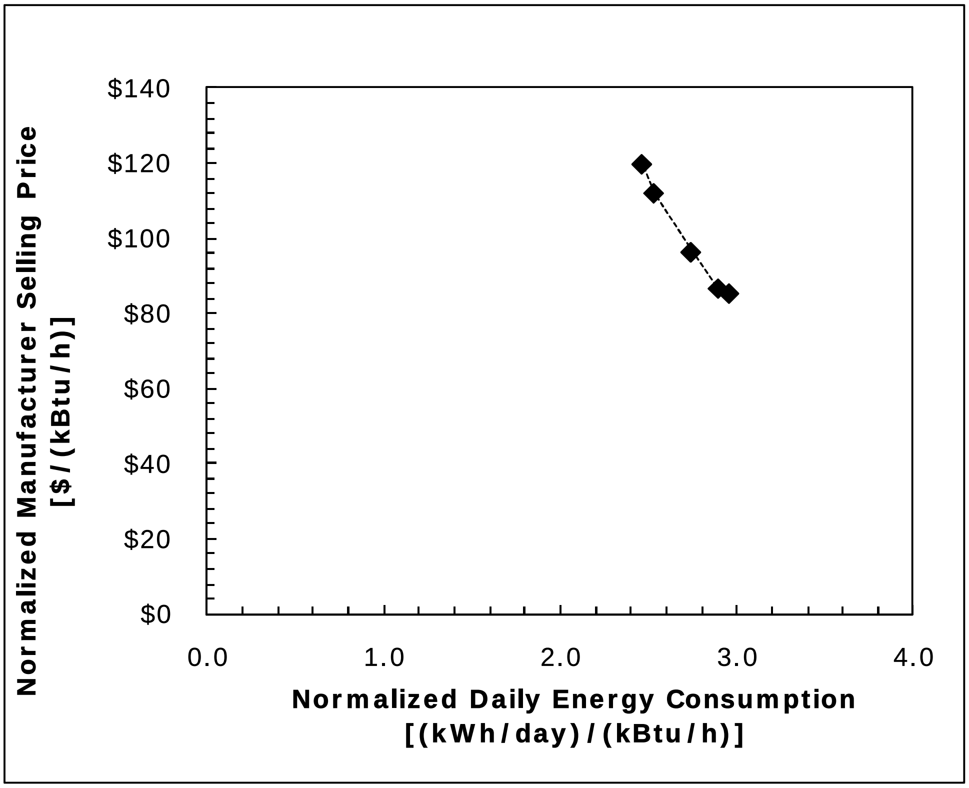

Figure 5.5.24 Cost-Efficiency Curve for the MC.L.I Equipment Class (Large)

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[iii] Other insulation products such as expanded polystyrene, polyisocyanurate and polyurethane board stocks are also used in WICF construction.

[iv] Downing, C.C. and Meffert, W.A, "Effectiveness of Cold-Storage Door Infiltration Protective Devices," 3726 (RP-645), ASHRAE Transactions: Research, 1993

[v] Downing, C.C. and Meffert, W.A, "Effectiveness of Cold-Storage Door Infiltration Protective Devices," 3726 (RP-645), ASHRAE Transactions: Research, 1993, p. 359

[vi] Downing, C.C. and Meffert, W.A, "Effectiveness of Cold-Storage Door Infiltration Protective Devices," 3726 (RP-645), ASHRAE Transactions: Research, 1993, p. 359

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[xii] The EER values were assumed based on values specified in the WICF Test procedure NOPR

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